THE ECG MONITORING AND DECISION SUPPORT SYSTEM

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Agenda

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- ECG signal and arrhythmias
- Literature review
- Dataset description
- ML Pipeline
- Feature extraction
- Machine learning models (decision tree, KNN, random forest and gradient boosting)
- Deep learning models
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    - Attention Time Incremented- Convolution Neural Network (ATI-CNN)
    - Convolution Neural Network-MaxPool
    - ResNet and Pretrained ResNet Model
- Performance Summary and Conclusion

Project Objective

- Work done in this project is towards the software design of a portable ECG (Electrocardiogram) machine, which will record heartbeat of a patient and detect the presence of Arrhythmias
- Objective was to train classifiers and Deep Learning architectures that can accurately identify presence of different types of arrhythmias
- Benefits of portable ECGs:
    - Availability in ambulances, public places, and for home monitoring
    - Remote monitoring in rural areas and collaboration with experts

1 in 4 deaths in India are attributed to CVDs

4-fold increase in CVDs over the past 40 years

Low per capita availability of Cardiologists

* Source: who.int, nih.gov

Literature Work

- The research paper used MultiLead Branch Fusion Network(Convo layers, RNN, Attention mechanism) based upon 12 lead ECG signal and achieved an accuracy of 84.6%.
- Another paper focused upon importance of temporal and spatial features of ECG signal and used Attention based Time Increment CNN network and witnessed accuracy of 83.78%.
- In one of the research papers, Transfer Learning was used for classification of Arrhythmias using pretrained Resnet architecture,which was trained on the same dataset that we are using for our classification problem.

ECG signal and Arrhythmias

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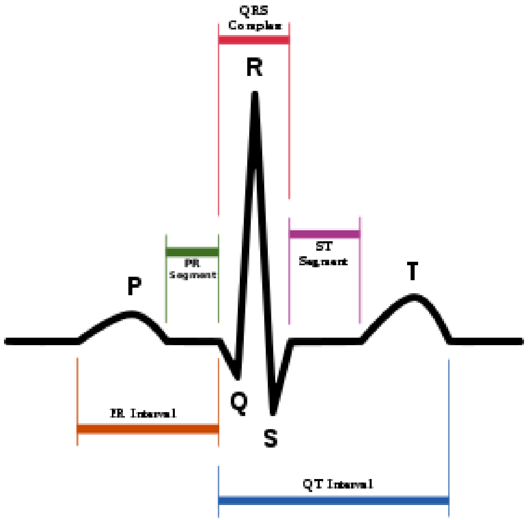
- Arrhythmia refers to any disturbance in the rate, regularity, site of origin, or conduction of cardiac electrical impulses
- ECG signal is a graphical representation of heart pulses (**voltage vs time**) captured using electrodes placed on the skin
- ECG can be analyzed by studying waveform components - P, Q, R, S, T
- Typically, 12 leads are used to analyze an ECG - 6 limb leads & 6 chest leads

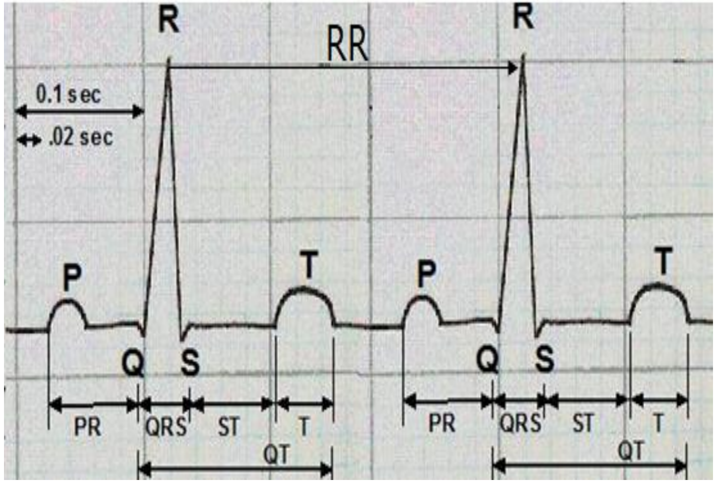
Components of ECG Signal



ECG signal and Arrhythmias

Arrhythmia Type	ECG components
1st degree atria ventricular block	QRS, P, T, RR
Atrial Fibrillation	P, RR
Right branch bundle block	QRS, S, T
Left Branch Bundle Block	QRS, T, R
Premature atrial contraction (PAC)	QRS, P
Premature ventricular contraction (PVC)	QRS, T
ST segment depression	ST
ST segment elevation	PR, ST

*Normal Sinus Rhythm is the healthy heart condition



Dataset description

- **Data Source:** China Physiological Signal Challenge 2018
- **Data Description**
  - Total recordings: 6877
  - Recording duration: 6 seconds to 60 seconds
  - Labels: 9 classes corresponding to 8 types of arrhythmias and 1 normal rhythm
- **Data Selected for 6-lead portable ECG device**
  - Sampling frequency: 500 Hz
  - Leads: II, V1, V2, V3, V5, V6
  - Training set corresponding to 5682 recordings
  - Labels: 7 classes (Atrial Fibrillation and Left Bundle Branch Block dropped)

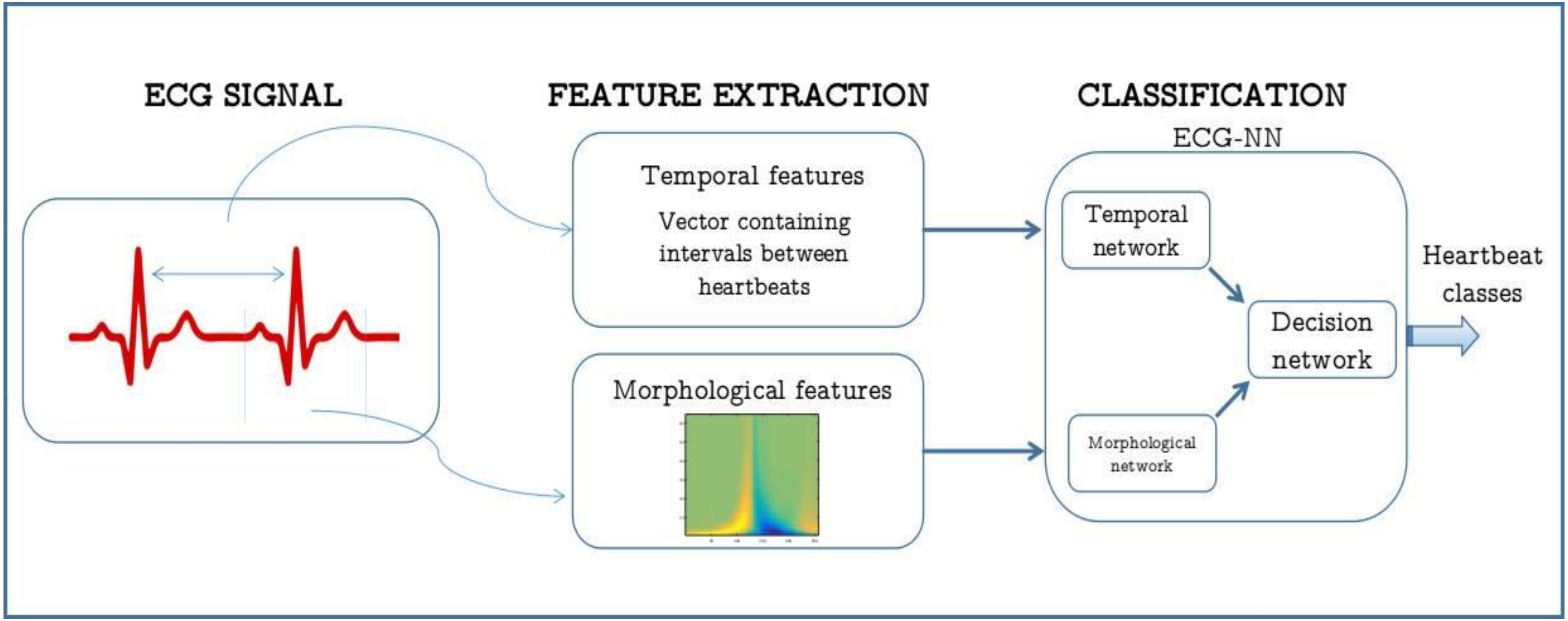
Arrhythmia Type	Recordings
Normal Sinus Rhythm	918
1st degree atrial ventricular block	722
Right Bundle Branch Block	1857
Premature atrial contraction	617
Premature ventricular contraction	700
ST segment depression	869
ST segment elevation	220

ML Pipeline

Data Pre-processing → Feature extraction → Feature scaling → Model training → Model validation

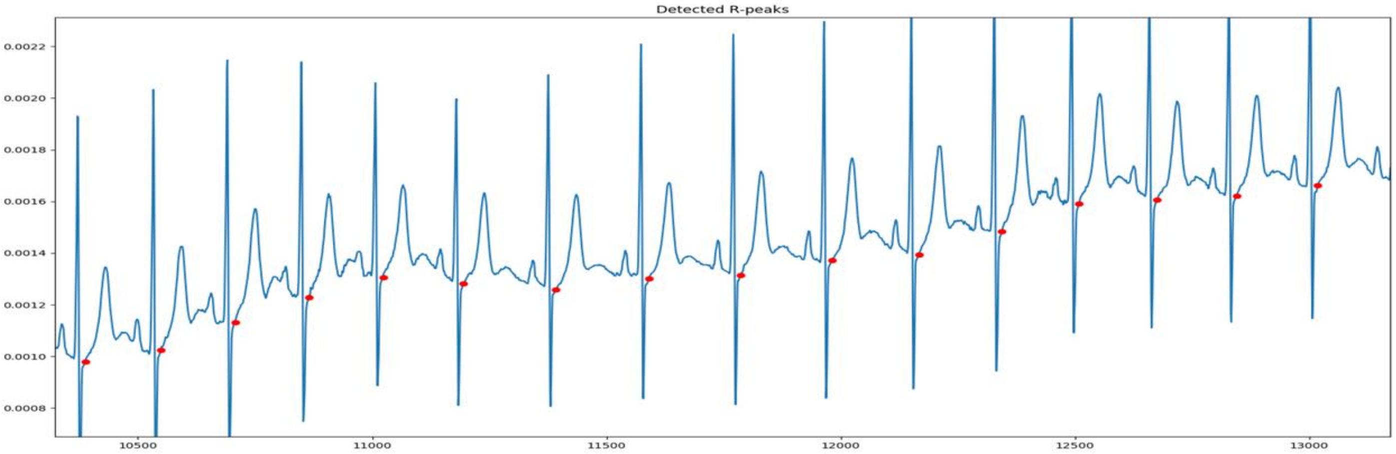
- Features extracted for 6-leads and merged together
- Scaling using standard scalar (MinMax scalar accuracy was much lower)
- Train-test split at 80:20
- Multi-label classification done using following models:
  - K-Nearest Neighbors (KNN)
  - Decision Tree
  - Random Forest
  - Gradient Boosting Classifier

Approach to Feature Extraction



HRV (Heart Rate Variability)

- Features extracted using this module for 6 leads
- hrv is a simple Python module that brings the most widely used techniques to work with RR intervals and Heart Rate Variability (HRV) analyses.



Temporal Features

They actually pertain to time variance of the signal:-
Some mathematical operations are being performed to the RR interval and these were used as temporal features. These are:-

mean rr, standard deviation rr, number of pairs of successive rr that differ by >50 ms (nn50), percentage of nn50 to total rr intervals, minimum heart rate, maximum heart rate, mean heart rate, standard deviation of heart rate

Morphological Features

They pertain to the shape of waveform.
Features used in this are the **wavelet transformation, local binary pattern and high order statistics.**

What is a wavelet and why we need this?

- ➔ A wavelet is a mathematical function useful in digital signal processing and image compression
- ➔ Wavelet Transform provides localization in both time and frequency.
- ➔ In preprocessing stage, DWT is used to remove the baseline wander in the ECG signal.
- ➔ It used to divide a given function or continuous-time signal into different scale components.
- ➔ Wavelet analysis is localized both in time domain and frequency domain.

Local Binary Pattern

Local Binary Pattern (LBP) is an effective texture descriptor for images which thresholds the neighboring pixels based on the value of the current pixel. LBP descriptors efficiently capture the local spatial patterns and the gray scale contrast in an image.

Higher order statistics

First, the wavelet package coefficients (WPC) are calculated for each different type of ECG beat. Then, higher order statistics of WPC are derived.

Decision Tree

Base Model

(fully-grown trees using sklearn)

Train accuracy: 98.7%
Test accuracy: 53.2%
Precision: 0.54
Recall: 0.53
f1 score: 0.53

Over-fitting

Hyperparameter Tuning

(pruned to reduce max-depth of 4)

Train accuracy: 56.0%
Test accuracy: 49.8%
Precision: 0.49
Recall: 0.50
f1 score: 0.47

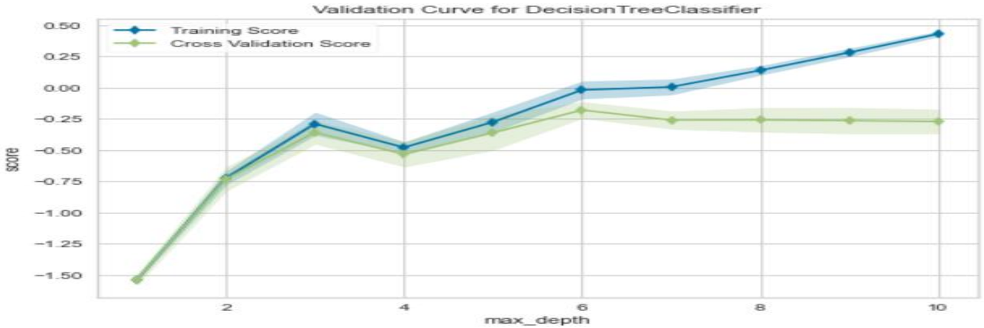
Lower accuracy

Hyperparameter Tuning

(multiple parameters optimized using Grid Search)

Train accuracy: 58.5%
Test accuracy: 58.0%
Precision: 0.58
Recall: 0.58
f1 score: 0.57

Final accuracy



Note: (1) Features extracted for 6 leads were use to train Decision Tree model
(2) Feature scaling was done using StandardScalar (accuracy for MinMaxScalar was lower)
(3) Train test ratio was 80:20

Sensitivity: Internal (C3)

KNN Model

- KNN is a classification algorithm that predicts based on majority label of “k” closest points
- Choosing a k affects the predicted values

Base Model (k=1)

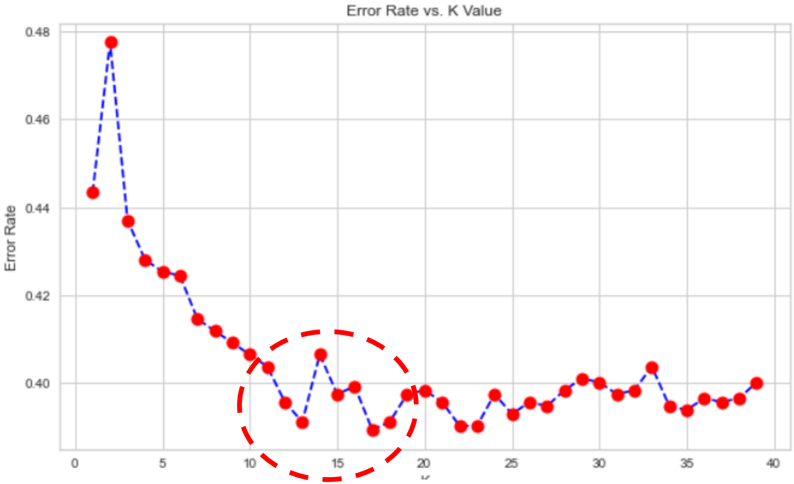
Train accuracy: 98.7%

Test accuracy: 55.6%

Precision: 0.54

Recall: 0.53

f1 score: 0.53



Revised Model (k=17)

Train accuracy: 65.7%

Test accuracy: 61.8%

Precision: 0.63

Recall: 0.61

f1 score: 0.59

Sensitivity: Internal (C3)

Random Forest and Gradient Boosting

Random Forest

Train accuracy: 98.6% → 68.2%

Test accuracy: 69.3% → 63.1%

Precision: 0.69 → 0.63

Recall: 0.70 → 0.63

f1 score: 0.68 → 0.59

Hyperparameters tuning:

max depth (5)

n_estimators (50)

Gradient Boosting

Train accuracy: 70.3%

Test accuracy: 60.2%

Precision: 0.59

Recall: 0.60

f1 score: 0.59

Hyperparameters tuning:

max depth (2)

n_estimators (30)

More work to be done on feature extraction to increase model accuracy

Sensitivity: Internal (C3)

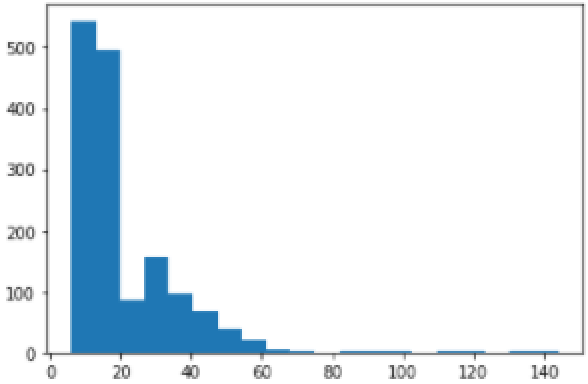
DEEP NEURAL NETWORKS

Data Preprocessing → Model Building → Evaluation

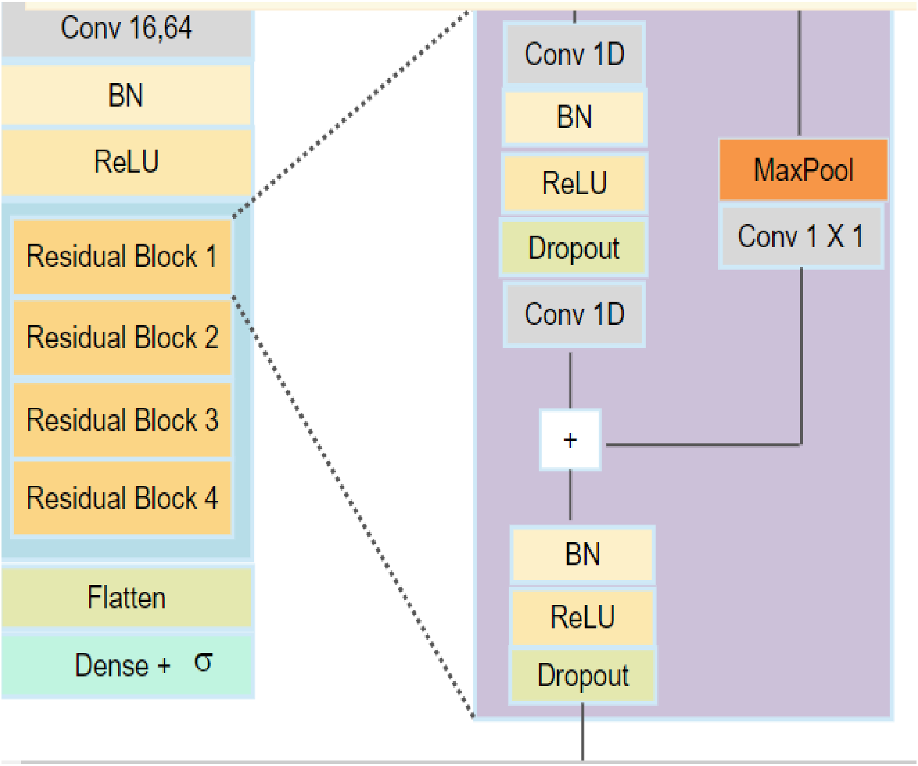
Data Preprocessing

- 6 Lead ECG signal are of shape(n_points,n_leads) where n_points are sampled at 500 Hz frequency.

- Signals greater than 60 sec were dropped from the dataset and hence remaining signals were of 6 to 60 sec timings and therefore, were padded with zeros to make them of equal length (30000,6).



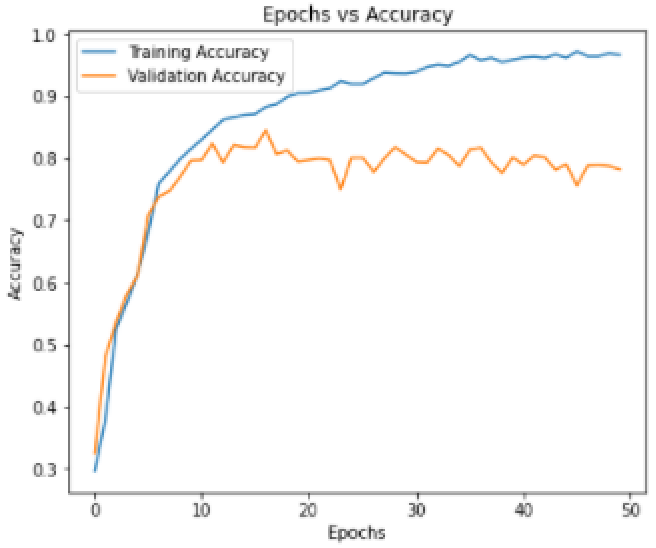
1. Res-net Model



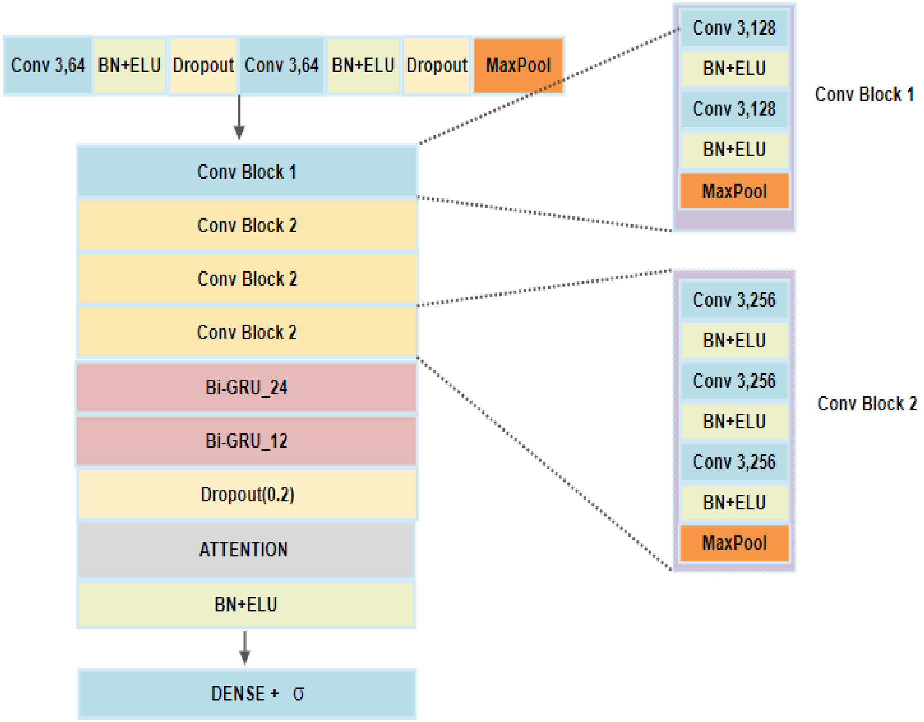
- It has 4 residual blocks,each residual block consists of a skip connection in order to avoid overfitting.
- ReLU activation function is used
- There is a fully connected Dense layer with 7 neurons and sigmoid activation function

Performance

- Batch Size : 64
- Learning Rate : 0.001
- Optimizer : ADAM
- **Testing Accuracy** : 79.20%
- Epochs : 50



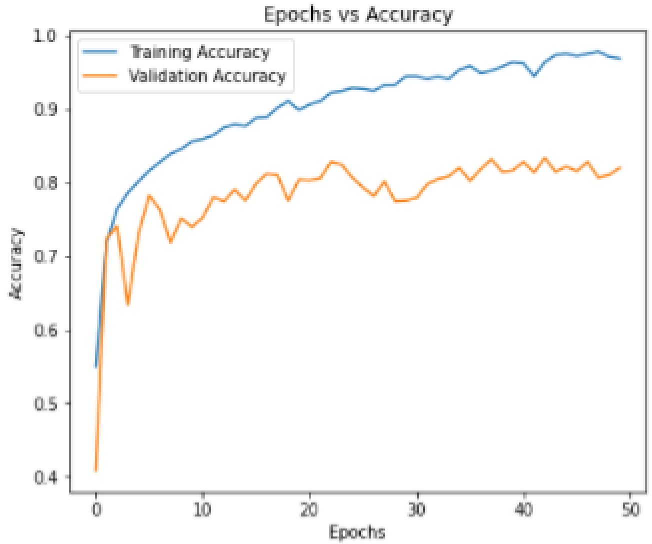
2. ATI-CNN



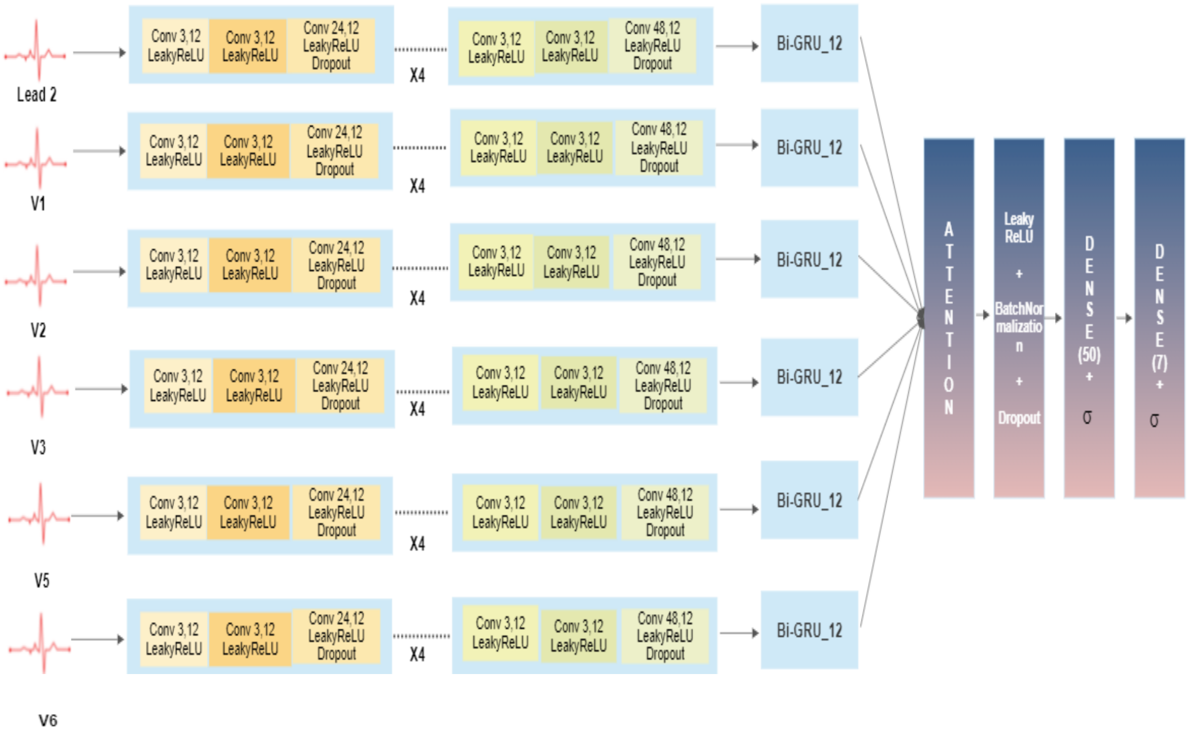
- This model basically focus on spatial and temporal feature of ECG signal.
- Convolution Blocks extracts spatial feature and 2 Bi-GRU are used to extract temporal features
- ELU activation function is used

Performance

- Batch Size : 32
- Learning Rate : 0.001
- Optimizer : ADAM
- **Testing Accuracy** : 82.04%
- Epochs : 50

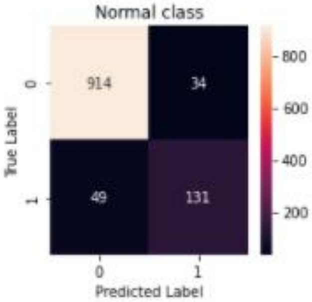


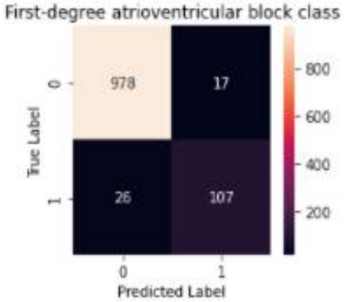
3. MLBF Net

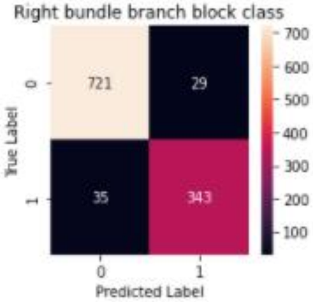


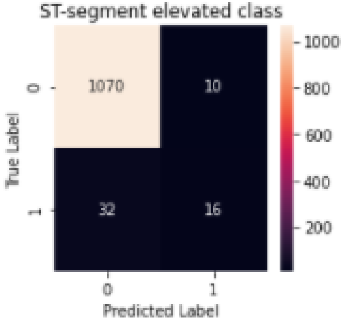
- This model learns Lead specific features.
- Those Lead specific diverse features are concatenated and passed through Attention Layer.
- LeakyReLU activation

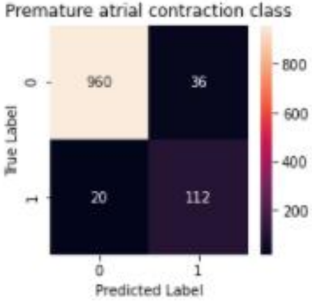
Confusion Matrix

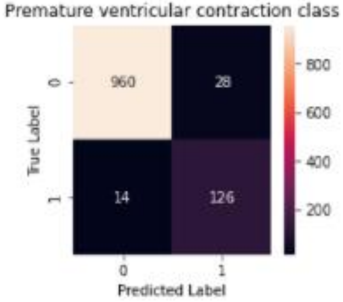


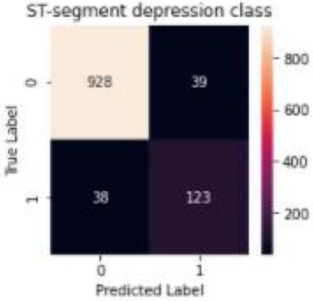






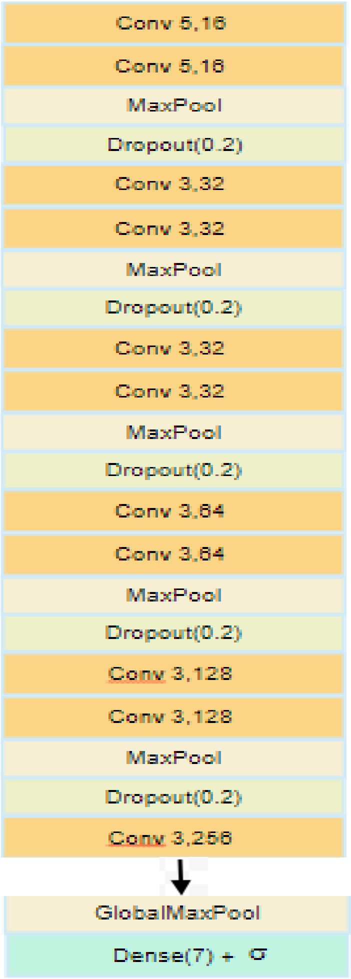






- **Testing Accuracy** : 85.34%
- F1 Score: 0.82

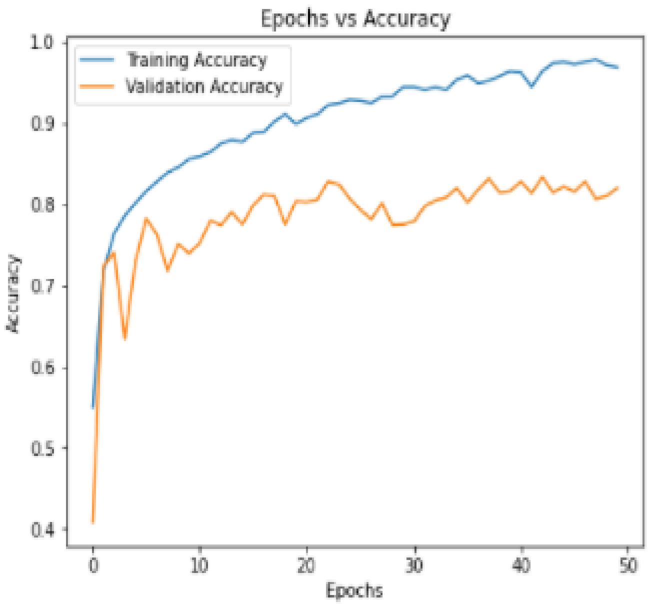
4.CNN-Maxpool



- It consists of 11 convolution layers,5 maxpool layers and one global maxpool layer.
- It uses ReLU activation function
- Dropout rate of 0.2 is used.

Performance

- Batch Size : 64
- Learning Rate : 0.001
- Optimizer : ADAM
- **Validation Accuracy** : 80.20%
- Epochs : 50



Transfer Learning

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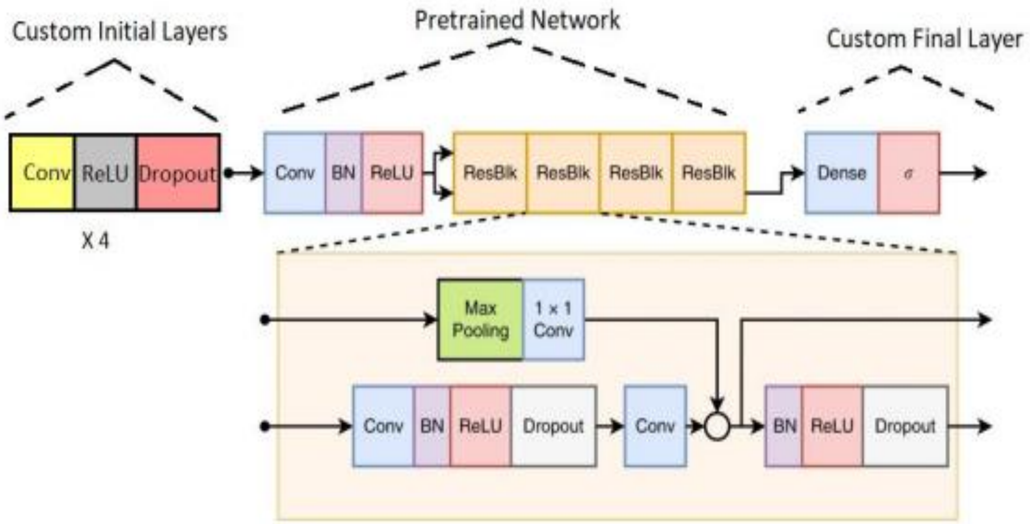
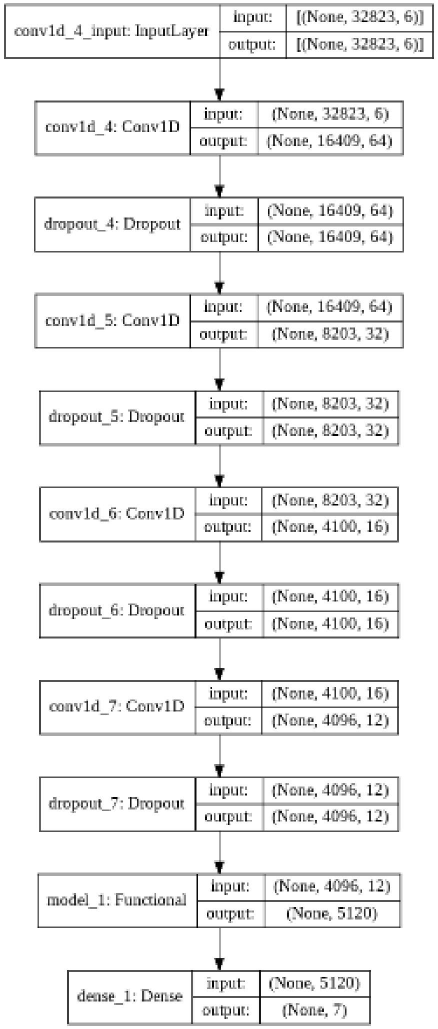
- It is a research problem in ML that focuses on storing knowledge gained while solving one problem and applying it to a different but related problem.

- Training a deep neural network from scratch requires a lot of computational resources and a large dataset ,therefore transfer learning comes to rescue.

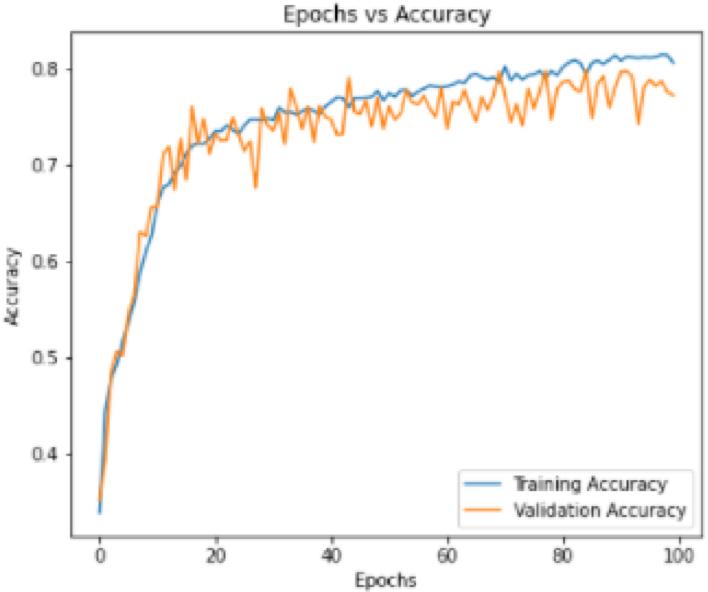
Pretrained Resnet Model





Performance

- Batch Size : 64
- Learning Rate : 0.01
- Optimizer : ADAM
- **Validation Accuracy** : 77.54%
- Epochs : 100



Performance Summary

Model	Training Accuracy	Test Accuracy	Precision, Recall, F1_Score
MLBF	94.1%	85.3%	0.82, 0.82, 0.82
ATI-CNN	94.3%	82.0%	0.81, 0.78. 0.78
CNN-Maxpool	95.5%	80.2%	0.82, 0.74, 0.77
ResNet	95.5%	78.3%	0.82, 0.73, 0.71
Pretrained ResNet	84.3%	77.5%	0.65, 0.64, 0.64
KNN	65.7%	61.8%	0.63, 0.61, 0.59
Decision Tree	58.5%	58.0%	0.58, 0.58, 0.57
Random Forest	68.2%	63.1%	0.62, 0.62, 0.59
Gradient Boosting	70.3%	60.2%	0.59, 0.60, 0.60

MLBF seems to be the best model due to following:

- Lead specific Features
- Extracts both spatial and temporal features.

https://github.com/Anupriya-Sri/ECG-monitoring-and-decision-support-system

Future Scope

- Additional features to increase accuracy and DL models to be trained using pre-processed features
- Increasing dataset and collect real-life data set
- Integrating software models to the hardware device
- Extend this 6 lead classification problem to 12 lead.

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Thank You