```
!pip install tensorflow
!pip install wfdb
!pip install h5py
!pip install tensorflow-gpu
!pip install keras
!pip install seaborn
!pip install scipy
!pip install scikit-learn
!pip install prettytable
!pip install numpy
```

```
Requirement already satisfied: pillow>=6.2.0 in /usr/local/lib/python3.10/dist-packages (from matplotlib>=3.2.2->wfdb) (9.4.0)
Requirement already satisfied: pyparsing>=2.3.1 in /usr/local/lib/python3.10/dist-packages (from matplotlib>=3.2.2->wfdb) (3.1.1)
Requirement already satisfied: python-dateutil>=2.7 in /usr/local/lib/python3.10/dist-packages (from matplotlib>=3.2.2->wfdb) (2.
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.10/dist-packages (from pandas>=1.3.0->wfdb) (2023.3.post1)
Requirement already satisfied: charset-normalizer<4,>=2 in /usr/local/lib/python3.10/dist-packages (from requests>=2.8.1->wfdb) (
Requirement already satisfied: idna<4,>=2.5 in /usr/local/lib/python3.10/dist-packages (from requests>=2.8.1->wfdb) (3.4)
Requirement already satisfied: urllib3<3,>=1.21.1 in /usr/local/lib/python3.10/dist-packages (from requests>=2.8.1->wfdb) (2.0.7)
Requirement already satisfied: certifi>=2017.4.17 in /usr/local/lib/python3.10/dist-packages (from requests>=2.8.1->wfdb) (2023.7
Requirement already satisfied: cffi>=1.0 in /usr/local/lib/python3.10/dist-packages (from SoundFile>=0.10.0->wfdb) (1.16.0)
Requirement already satisfied: pycparser in /usr/local/lib/python3.10/dist-packages (from cffi>=1.0->SoundFile>=0.10.0->wfdb) (2.
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.7->matplotlib>=3.2.2-
Installing collected packages: wfdb
Successfully installed wfdb-4.1.2
Requirement already satisfied: h5py in /usr/local/lib/python3.10/dist-packages (3.9.0)
Requirement already satisfied: numpy>=1.17.3 in /usr/local/lib/python3.10/dist-packages (from h5py) (1.23.5)
Collecting tensorflow-gpu
  Downloading tensorflow-gpu-2.12.0.tar.gz (2.6 kB)
  error: subprocess-exited-with-error

  × python setup.py egg_info did not run successfully.
  │ exit code: 1
  ╰─> See above for output.

  note: This error originates from a subprocess, and is likely not a problem with pip.
  Preparing metadata (setup.py) ... error
error: metadata-generation-failed

× Encountered error while generating package metadata.
╰─> See above for output.

note: This is an issue with the package mentioned above, not pip.
hint: See above for details.
Requirement already satisfied: keras in /usr/local/lib/python3.10/dist-packages (2.14.0)
Requirement already satisfied: seaborn in /usr/local/lib/python3.10/dist-packages (0.12.2)
Requirement already satisfied: numpy!=1.24.0,>=1.17 in /usr/local/lib/python3.10/dist-packages (from seaborn) (1.23.5)
Requirement already satisfied: pandas>=0.25 in /usr/local/lib/python3.10/dist-packages (from seaborn) (1.5.3)
Requirement already satisfied: matplotlib!=3.6.1,>=3.1 in /usr/local/lib/python3.10/dist-packages (from seaborn) (3.7.1)
Requirement already satisfied: contourpy>=1.0.1 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seaborn
Requirement already satisfied: cycler>=0.10 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seaborn) (0
Requirement already satisfied: fonttools>=4.22.0 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seabor
Requirement already satisfied: kiwisolver>=1.0.1 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seabor
Requirement already satisfied: packaging>=20.0 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seaborn)
Requirement already satisfied: pillow>=6.2.0 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seaborn) (
Requirement already satisfied: pyparsing>=2.3.1 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->seaborn
Requirement already satisfied: python-dateutil>=2.7 in /usr/local/lib/python3.10/dist-packages (from matplotlib!=3.6.1,>=3.1->sea
Requirement already satisfied: pytz>=2020.1 in /usr/local/lib/python3.10/dist-packages (from pandas>=0.25->seaborn) (2023.3.post1
Requirement already satisfied: six>=1.5 in /usr/local/lib/python3.10/dist-packages (from python-dateutil>=2.7->matplotlib!=3.6.1,
Requirement already satisfied: scipy in /usr/local/lib/python3.10/dist-packages (1.11.3)
Requirement already satisfied: numpy<1.28.0,>=1.21.6 in /usr/local/lib/python3.10/dist-packages (from scipy) (1.23.5)
Requirement already satisfied: scikit-learn in /usr/local/lib/python3.10/dist-packages (1.2.2)
Requirement already satisfied: numpy>=1.17.3 in /usr/local/lib/python3.10/dist-packages (from scikit-learn) (1.23.5)
Requirement already satisfied: scipy>=1.3.2 in /usr/local/lib/python3.10/dist-packages (from scikit-learn) (1.11.3)
Requirement already satisfied: joblib>=1.1.1 in /usr/local/lib/python3.10/dist-packages (from scikit-learn) (1.3.2)
Requirement already satisfied: threadpoolctl>=2.0.0 in /usr/local/lib/python3.10/dist-packages (from scikit-learn) (3.2.0)
Requirement already satisfied: prettytable in /usr/local/lib/python3.10/dist-packages (3.9.0)
Requirement already satisfied: wcwidth in /usr/local/lib/python3.10/dist-packages (from prettytable) (0.2.9)
Requirement already satisfied: numpy in /usr/local/lib/python3.10/dist-packages (1.23.5)
```

```
! rm -r *
!ls
!wget https://physionet.org/static/published-projects/qtdb/qt-database-1.0.0.zip
!wget https://physionet.org/static/published-projects/nstdb/mit-bih-noise-stress-test-database-1.0.0.zip
!ls
print('Downloading data: Done')

!mkdir data
!unzip qt-database-1.0.0.zip >> /dev/null
!unzip mit-bih-noise-stress-test-database-1.0.0.zip >> /dev/null
!mv qt-database-1.0.0 data/
!mv mit-bih-noise-stress-test-database-1.0.0 data/
!rm qt-database-1.0.0.zip
!rm mit-bih-noise-stress-test-database-1.0.0.zip
!ls
```

```
!ls data
print('Extracting data: Done')
```

```
--2023-11-15 14:00:05--  https://physionet.org/static/published-projects/qtdb/qt-database-1.0.0.zip
Resolving physionet.org (physionet.org)... 18.18.42.54
Connecting to physionet.org (physionet.org)|18.18.42.54|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 87119682 (83M) [application/zip]
Saving to: ‘qt-database-1.0.0.zip’

qt-database-1.0.0.z 100%[===================>]  83.08M  1.65MB/s    in 54s

2023-11-15 14:00:59 (1.55 MB/s) - ‘qt-database-1.0.0.zip’ saved [87119682/87119682]

--2023-11-15 14:00:59--  https://physionet.org/static/published-projects/nstdb/mit-bih-noise-stress-test-database-1.0.0.zip
Resolving physionet.org (physionet.org)... 18.18.42.54
Connecting to physionet.org (physionet.org)|18.18.42.54|:443... connected.
HTTP request sent, awaiting response... 200 OK
Length: 70945297 (68M) [application/zip]
Saving to: ‘mit-bih-noise-stress-test-database-1.0.0.zip’

mit-bih-noise-stres 100%[===================>]  67.66M  1.74MB/s    in 43s

2023-11-15 14:01:42 (1.56 MB/s) - ‘mit-bih-noise-stress-test-database-1.0.0.zip’ saved [70945297/70945297]

mit-bih-noise-stress-test-database-1.0.0.zip  qt-database-1.0.0.zip
Downloading data: Done
data
mit-bih-noise-stress-test-database-1.0.0  qt-database-1.0.0
Extracting data: Done
```

```
import glob
import numpy as np
from scipy.signal import resample_poly
import wfdb
import math
import _pickle as pickle
import matplotlib.pyplot as plt


QTpath='data/qt-database-1.0.0/'
# Desired sampling frecuency
newFs = 360

# Preprocessing signals
namesPath = glob.glob(QTpath + "/*.dat")

# final list that will contain all signals and beats processed
QTDatabaseSignals = dict()

register_name = None
for i in namesPath:

    # reading signals
    aux = i.split('.dat')
    register_name = aux[0].split('/')[-1]
    signal, fields = wfdb.rdsamp(aux[0])
    qu = len(signal)

    # reading annotations
    ann = wfdb.rdann(aux[0], 'pu1')
    anntype = ann.symbol
    annSamples = ann.sample

    # Obtaining P wave start positions
    Anntype = np.array(anntype)
    idx = Anntype == 'p'
    Pidx = annSamples[idx]
    idxS = Anntype == '('
    Sidx = annSamples[idxS]
    idxR = Anntype == 'N'
    Ridx = annSamples[idxR]
    ind = np.zeros(len(Pidx))

    for j in range(len(Pidx)):
        arr = np.where(Pidx[j] > Sidx)
        arr = arr[0]
        ind[j] = arr[-1]

    ind = ind.astype(np.int64)
    Pstart = Sidx[ind]

    # Shift 40ms before P wave start
    Pstart = Pstart - int(0.04*fields['fs'])
```

```
        # Extract first channel
        auxSig = signal[0:qu, 0]

        # Beats separation and removing outliers
        # Beats separation and removal of the vectors that contain more or equal than
        # two beats based on QRS annotations
        beats = list()
        for k in range(len(Pstart)-1):
            remove = (Ridx > Pstart[k]) & (Ridx < Pstart[k+1])
            if np.sum(remove) < 2:
                beats.append(auxSig[Pstart[k]:Pstart[k+1]])

        # Creating the list that will contain each beat per signal
        beatsRe = list()

        # processing each beat
        for k in range(len(beats)):
            # Padding data to avoid edge effects caused by resample
            L = math.ceil(len(beats[k])*newFs/fields['fs'])
            normBeat = list(reversed(beats[k])) + list(beats[k]) + list(reversed(beats[k]))

            # resample beat by beat and saving it
            res = resample_poly(normBeat, newFs, fields['fs'])
            res = res[L-1:2*L-1]
            beatsRe.append(res)

        # storing all beats in each corresponding signal, list of list
        QTDatabaseSignals[register_name] = beatsRe

    # Save Data
    with open('data/QTDatabase.pkl', 'wb') as output:  # Overwrites any existing file.
        pickle.dump(QTDatabaseSignals, output)
    print('============================================================')
    print('MIT QT database saved as pickle file')
```

```
    ============================================================
    MIT QT database saved as pickle file
```

```
    NSTDBPath = 'data/mit-bih-noise-stress-test-database-1.0.0/bw'
    signals, fields = wfdb.rdsamp(NSTDBPath)

    for key in fields:
        print(key, fields[key])

    np.save('data/NoiseBWL', signals)

    with open('data/NoiseBWL.pkl', 'wb') as output:
        pickle.dump(signals, output)
    print('============================================================')
    print('MIT BIH data noise stress test database (NSTDB) saved as pickle')
```

```
    fs 360
    sig_len 650000
    n_sig 2
    base_date None
    base_time None
    units ['mV', 'mV']
    sig_name ['noise1', 'noise2']
    comments []
    ============================================================
    MIT BIH data noise stress test database (NSTDB) saved as pickle
```

```
    NSTDBPath = 'data/mit-bih-noise-stress-test-database-1.0.0/ma'
    signals, fields = wfdb.rdsamp(NSTDBPath)

    for key in fields:
        print(key, fields[key])

    np.save('data/NoiseMA', signals)
    # Save Data
    with open('data/NoiseMA.pkl', 'wb') as output:
        pickle.dump(signals, output)
    print('============================================================')
    print('MIT BIH data noise stress test database (NSTDB) saved as pickle')
```

```
    fs 360
    sig_len 650000
    n_sig 2
    base_date None
    base_time None
    units ['mV', 'mV']
```

```
 sig_name ['noise1', 'noise2']
 comments []
 ==========================================================
 MIT BIH data noise stress test database (NSTDB) saved as pickle
```

```
NSTDBPath = 'data/mit-bih-noise-stress-test-database-1.0.0/em'
signals, fields = wfdb.rdsamp(NSTDBPath)

for key in fields:
    print(key, fields[key])

np.save('data/NoiseEM', signals)
# Save Data
with open('data/NoiseEM.pkl', 'wb') as output:
    pickle.dump(signals, output)
print('==========================================================')
print('MIT BIH data noise stress test database (NSTDB) saved as pickle')
```

```
fs 360
 sig_len 650000
 n_sig 2
 base_date None
 base_time None
 units ['mV', 'mV']
 sig_name ['noise1', 'noise2']
 comments []
 ==========================================================
 MIT BIH data noise stress test database (NSTDB) saved as pickle
```

```
print('Getting the Data ready ... ')

# The seed is used to ensure the ECG always have the same contamination level
# this enhance reproducibility
seed = 1234
np.random.seed(seed=seed)

# Load QT Database
with open('data/QTDatabase.pkl', 'rb') as input:
    # dict {register_name: beats_list}
    qtdb = pickle.load(input)

# Load NSTDB BWT
with open('data/NoiseBWL.pkl', 'rb') as input:
    nstdbwl = pickle.load(input)

# Load NSTDB MA
with open('data/NoiseMA.pkl', 'rb') as input:
    nstdma = pickle.load(input)

# Load NSTDB EN
with open('data/NoiseEM.pkl', 'rb') as input:
    nstdem = pickle.load(input)


# NSTDB

noise_channel1 = nstdbwl[:, 0]
noise_channel2 = nstdbwl[:, 1]

noise_channel3 = nstdma[:, 0]
noise_channel4 = nstdma[:, 1]
noise_channel5 = nstdem[:, 0]
noise_channel6 = nstdem[:, 1]


# Data split

noise_test_bwt = np.concatenate(
    (noise_channel1[0:int(noise_channel1.shape[0] * 0.13)], noise_channel2[0:int(noise_channel2.shape[0] * 0.13)]))
noise_train_bwt = np.concatenate((noise_channel1[int(noise_channel1.shape[0] * 0.13):-1],
                              noise_channel2[int(noise_channel2.shape[0] * 0.13):-1]))

noise_test_ma = np.concatenate(
    (noise_channel3[0:int(noise_channel3.shape[0] * 0.13)], noise_channel4[0:int(noise_channel4.shape[0] * 0.13)]))
noise_train_ma = np.concatenate((noise_channel3[int(noise_channel3.shape[0] * 0.13):-1],
                              noise_channel4[int(noise_channel4.shape[0] * 0.13):-1]))

noise_test_em = np.concatenate(
    (noise_channel5[0:int(noise_channel5.shape[0] * 0.13)], noise_channel6[0:int(noise_channel6.shape[0] * 0.13)]))
noise_train_em = np.concatenate((noise_channel5[int(noise_channel5.shape[0] * 0.13):-1],
                              noise_channel6[int(noise_channel6.shape[0] * 0.13):-1]))
```

```
# QTDatabase

beats_train = []
beats_test = []

test_set = ['sel123',  # Record from MIT-BIH Arrhythmia Database
            'sel233',  # Record from MIT-BIH Arrhythmia Database

            'sel302',  # Record from MIT-BIH ST Change Database
            'sel307',  # Record from MIT-BIH ST Change Database

            'sel820',  # Record from MIT-BIH Supraventricular Arrhythmia Database
            'sel853',  # Record from MIT-BIH Supraventricular Arrhythmia Database

            'sel16420',  # Record from MIT-BIH Normal Sinus Rhythm Database
             'sel16795',  # Record from MIT-BIH Normal Sinus Rhythm Database

            'sele0106',  # Record from European ST-T Database
            'sele0121',  # Record from European ST-T Database

            'sel32',  # Record from ``sudden death'' patients from BIH
            'sel49',  # Record from ``sudden death'' patients from BIH

            'sel14046',  # Record from MIT-BIH Long-Term ECG Database
            'sel15814',  # Record from MIT-BIH Long-Term ECG Database
            ]

# Creating the train and test dataset, each datapoint has 512 samples and is zero padded
# beats bigger that 512 samples are discarded to avoid wrong split beats ans to reduce
# computation.
skip_beats = 0
samples = 512
qtdb_keys = list(qtdb.keys())

for i in range(len(qtdb_keys)):
    signal_name = qtdb_keys[i]

    for b in qtdb[signal_name]:

        b_np = np.zeros(samples)
        b_sq = np.array(b)

        # There are beats with more than 512 samples (could be up to 3500 samples)
        # Creating a threshold of 512 - init_padding samples max. gives a good compromise between
        # the samples amount and the discarded signals amount
        # before:
        # train: 74448  test: 13362
        # after:
        # train: 71893 test: 13306  (discarded train: ~4k datapoints test: ~50)

        init_padding = 16
        if b_sq.shape[0] > (samples - init_padding):
           skip_beats += 1
           continue

        b_np[init_padding:b_sq.shape[0] + init_padding] = b_sq - (b_sq[0] + b_sq[-1]) / 2

        if signal_name in test_set:
            beats_test.append(b_np)
        else:
            beats_train.append(b_np)

# Noise was added in a proportion from 0.2 to 2 times the ECG signal amplitude
# Similar to
# W. Muldrow, R.G. Mark, & Moody, G. B. (1984).
# A noise stress test for arrhythmia detectors.
# Computers in Cardiology, 381–384

sn_train = []
sn_test = []

noise_index = 0

# Adding noise to train
rnd_train = np.random.randint(low=20, high=200, size=len(beats_train)) / 100
for i in range(len(beats_train)):
    beat_max_value = np.max(beats_train[i]) - np.min(beats_train[i])

    noise_bwt = noise_train_bwt[noise_index:noise_index + samples]
    noise_max_value_bwt = np.max(noise_bwt) - np.min(noise_bwt)
    Ase_bwt = noise_max_value_bwt / beat_max_value
```

```
        alpha = rnd_train[i] / Ase_bwt

        noise_ma = noise_train_ma[noise_index:noise_index + samples]
        noise_max_value_ma = np.max(noise_ma) - np.min(noise_ma)
        Ase_ma = noise_max_value_ma / beat_max_value
        beta = rnd_train[i] / Ase_ma

        noise_em = noise_train_bwt[noise_index:noise_index + samples]
        noise_max_value_em = np.max(noise_em) - np.min(noise_em)
        Ase_em = noise_max_value_em / beat_max_value
        gamma = rnd_train[i] / Ase_em

        signal_noise = beats_train[i] + alpha/3 * noise_bwt + beta/3 * noise_ma + gamma/3 * noise_em

        sn_train.append(signal_noise)
        noise_index += samples

        if noise_index > (len(noise_train_bwt) - samples):
            noise_index = 0

    # Adding noise to test
    noise_index = 0
    rnd_test = np.random.randint(low=20, high=200, size=len(beats_test)) / 100
    for i in range(len(beats_test)):
        beat_max_value = np.max(beats_test[i]) - np.min(beats_test[i])

        noise_bwt = noise_test_bwt[noise_index:noise_index + samples]
        noise_max_value_bwt = np.max(noise_bwt) - np.min(noise_bwt)
        Ase_bwt = noise_max_value_bwt / beat_max_value
        alpha = rnd_test[i] / Ase_bwt

        noise_ma = noise_test_ma[noise_index:noise_index + samples]
        noise_max_value_ma = np.max(noise_ma) - np.min(noise_ma)
        Ase_ma = noise_max_value_ma / beat_max_value
        beta = rnd_test[i] / Ase_ma

        noise_em = noise_test_bwt[noise_index:noise_index + samples]
        noise_max_value_em = np.max(noise_em) - np.min(noise_em)
        Ase_em = noise_max_value_em / beat_max_value
        gamma = rnd_test[i] / Ase_em

        signal_noise = beats_test[i] + alpha/3 * noise_bwt + beta/3 * noise_ma + gamma/3 * noise_em

        sn_test.append(signal_noise)
        noise_index += samples

        if noise_index > (len(noise_test_bwt) - samples):
           noise_index = 0

    X_train = np.array(sn_train)
    y_train = np.array(beats_train)

    X_test = np.array(sn_test)
    y_test = np.array(beats_test)

    X_train = np.expand_dims(X_train, axis=2)
    y_train = np.expand_dims(y_train, axis=2)

    X_test = np.expand_dims(X_test, axis=2)
    y_test = np.expand_dims(y_test, axis=2)

    Dataset = [X_train, y_train, X_test, y_test]

    print('Dataset ready to use.')
```

```
Getting the Data ready ...
Dataset ready to use.
```

```
    print("DATASET SHAPE")
    print(f'Training {X_train.shape}')
    print(f'Training {X_test.shape}')
```

```
DATASET SHAPE
Training (72002, 512, 1)
Training (13316, 512, 1)
```

```
    import keras
    from keras.models import Sequential, Model
    from keras.layers import Dense, Conv1D, Flatten, Dropout, BatchNormalization, concatenate, Activation, Input, Conv2DTranspose, Lambda, I

    import keras.backend as K
```

```
def Conv1DTranspose(input_tensor, filters, kernel_size, strides=2, activation='relu', padding='same'):
    x = Lambda(lambda x: K.expand_dims(x, axis=2))(input_tensor)
    x = Conv2DTranspose(filters=filters,
                        kernel_size=(kernel_size, 1),
                        activation=activation,
                        strides=(strides, 1),
                        padding=padding)(x)
    x = Lambda(lambda x: K.squeeze(x, axis=2))(x)
    return x


def FCN_DAE():
    # Implementation of FCN_DAE approach presented in
    # Chiang, H. T., Hsieh, Y. Y., Fu, S. W., Hung, K. H., Tsao, Y., & Chien, S. Y. (2019).
    # Noise reduction in ECG signals using fully convolutional denoising autoencoders.
    # IEEE Access, 7, 60806-60813.

    input_shape = (512, 1)
    input = Input(shape=input_shape)

    # Encoder
    x = Conv1D(filters=40,
               input_shape=(512, 1),
               kernel_size=16,
               activation='elu',
               strides=2,
               padding='same')(input)

    x = BatchNormalization()(x)

    x = Conv1D(filters=20,
                              kernel_size=16,
               activation='elu',
               strides=2,
               padding='same')(x)

    x = BatchNormalization()(x)

    x = Conv1D(filters=20,
               kernel_size=16,
               activation='elu',
               strides=2,
               padding='same')(x)

    x = BatchNormalization()(x)

    x = Conv1D(filters=20,
               kernel_size=16,
               activation='elu',
               strides=2,
               padding='same')(x)

    x = BatchNormalization()(x)

    x = Conv1D(filters=40,
               kernel_size=16,
               activation='elu',
               strides=2,
               padding='same')(x)

    x = BatchNormalization()(x)

    x = Conv1D(filters=1,
               kernel_size=16,
               activation='elu',
               strides=1,
               padding='same')(x)
    x = BatchNormalization()(x)

    # Decoder
    x = Conv1DTranspose(input_tensor=x,
                        filters=1,
                        kernel_size=16,
                        activation='elu',
                        strides=1,
                        padding='same')

    x = BatchNormalization()(x)

    x = Conv1DTranspose(input_tensor=x,
                        filters=40,
```

```
                        kernel_size=16,
                        activation='elu',
                        strides=2,
                        padding='same')

        x = BatchNormalization()(x)

        x = Conv1DTranspose(input_tensor=x,
                        filters=20,
                        kernel_size=16,
                        activation='elu',
                        strides=2,
                        padding='same')

        x = BatchNormalization()(x)

        x = Conv1DTranspose(input_tensor=x,
                        filters=20,
                        kernel_size=16,
                        activation='elu',
                        strides=2,
                        padding='same')
        x = BatchNormalization()(x)

        x = Conv1DTranspose(input_tensor=x,
                        filters=20,
                        kernel_size=16,
                        activation='elu',
                        strides=2,
                        padding='same')

        x = BatchNormalization()(x)

        x = Conv1DTranspose(input_tensor=x,
                        filters=40,
                        kernel_size=16,
                        activation='elu',
                        strides=2,
                        padding='same')

        x = BatchNormalization()(x)

        predictions = Conv1DTranspose(input_tensor=x,
                        filters=1,
                        kernel_size=16,
                        activation='linear',
                        strides=1,
                        padding='same')

        model = Model(inputs=[input], outputs=predictions)
        return model


    def DRRN_denoising():
        # Implementation of DRNN approach presented in
        # Antczak, K. (2018). Deep recurrent neural networks for ECG signal denoising.
        # arXiv preprint arXiv:1807.11551.

        model = Sequential()
        model.add(LSTM(64, input_shape=(512, 1), return_sequences=True))
        model.add(Dense(64, activation='relu'))
        model.add(Dense(64, activation='relu'))
        model.add(Dense(1, activation='linear'))

        return model



    import keras
    from keras import backend as K
    from keras.callbacks import ModelCheckpoint, ReduceLROnPlateau, EarlyStopping, TensorBoard
    from keras import losses
    from sklearn.model_selection import train_test_split

    def ssd_loss(y_true, y_pred):
        return K.sum(K.square(y_pred - y_true), axis=-2)

    def train_dl(Dataset, experiment):

        print('Deep Learning pipeline: Training the model for exp ' + str(experiment))

        [X_train, y_train, X_test, y_test] = Dataset
```

```
        X_train, X_val, y_train, y_val = train_test_split(X_train, y_train, test_size=0.3, shuffle=True, random_state=1)

        if experiment == 'FCN-DAE':
            # FCN_DAE
            model = FCN_DAE()
            model_label = 'FCN_DAE'
            criterion = ssd_loss

        if experiment == 'DRNN':
            # DRNN
            model = DRRN_denoising()
            model_label = 'DRNN'
            criterion = keras.losses.mean_squared_error

        print('\n ' + model_label + '\n ')

        model.summary()
        epochs = 100
        batch_size = 128
        lr = 1e-3
        minimum_lr = 1e-10


        model.compile(loss=criterion,
                      optimizer=keras.optimizers.Adam(lr=lr),
                      metrics=[losses.mean_squared_error, ssd_loss])

        # checkpoint
        model_filepath = model_label + '_weights.best.hdf5'

        checkpoint = ModelCheckpoint(model_filepath,
                                     monitor="val_loss",
                                     verbose=1,
                                     save_best_only=True,
                                     mode='min',
                                     save_weights_only=True)

        reduce_lr = ReduceLROnPlateau(monitor="val_loss",
                                      factor=0.5,
                                      min_delta=0.05,
                                      mode='min',
                                      patience=2,
                                      min_lr=minimum_lr,
                                      verbose=1)

        early_stop = EarlyStopping(monitor="val_loss",
                                   min_delta=0.05,
                                   mode='min',
                                   patience=10,
                                   verbose=1)

        model.fit(x=X_train, y=y_train,
                  validation_data=(X_val, y_val),
                  batch_size=batch_size,
                  epochs=epochs,
                               verbose=1,
                  callbacks=[checkpoint, reduce_lr, early_stop])

        K.clear_session()



    def test_dl(Dataset, experiment):

        print('Deep Learning pipeline: Testing the model')

        [train_set, train_set_GT, X_test, y_test] = Dataset

        batch_size = 32

        if experiment == 'FCN-DAE':
            # FCN_DAE
            model = FCN_DAE()
            model_label = 'FCN_DAE'
            criterion = ssd_loss

        if experiment == 'DRNN':
            # DRNN
            model = DRRN_denoising()
            model_label = 'DRNN'
            criterion = keras.losses.mean_squared_error
```

```
        print('\n ' + model_label + '\n ')

        model.summary()

        model.compile(loss=criterion,
                      optimizer=keras.optimizers.Adam(lr=0.01),
                      metrics=[keras.losses.mean_squared_error, ssd_loss])

        # checkpoint
        model_filepath = model_label + '_weights.best.hdf5'
        # load weights
        model.load_weights(model_filepath)

        # Test score
        y_pred = model.predict(X_test, batch_size=batch_size, verbose=1)


        K.clear_session()

        return [X_test, y_test, y_pred]


    dl_experiments = ['DRNN',
                      'FCN-DAE'
                      ]



    for experiment in range(len(dl_experiments)):
        train_dl(Dataset, dl_experiments[experiment])

        [X_test, y_test, y_pred] = test_dl(Dataset, dl_experiments[experiment])

        test_results = [X_test, y_test, y_pred]

        # Save Results
        with open('test_results_' + dl_experiments[experiment] + '.pkl', 'wb') as output:
            pickle.dump(test_results, output)

        print('Results from experiment ' + dl_experiments[experiment] + ' saved')
```

```
 lambda_13 (Lambda)          (None, 512, 1)            0

=================================================================
Total params: 80787 (315.57 KB)
Trainable params: 80223 (313.37 KB)
Non-trainable params: 564 (2.20 KB)
_________________________________________________________________
WARNING:absl:`lr` is deprecated in Keras optimizer, please use `learning_rate` or use the legacy optimizer, e.g.,tf.keras.optimiz
Epoch 1/100
394/394 [==============================] - ETA: 0s - loss: 38.2215 - mean_squared_error: 0.0747 - ssd_loss: 38.2215
Epoch 1: val_loss improved from inf to 37.70532, saving model to FCN_DAE_weights.best.hdf5
394/394 [==============================] - 152s 373ms/step - loss: 38.2215 - mean_squared_error: 0.0747 - ssd_loss: 38.2215 - val
```

```
from sklearn.metrics import mean_squared_error

def SSD(y, y_pred):
    return np.sum(np.square(y - y_pred), axis=1)

def MAD(y, y_pred):
    return np.max(np.abs(y - y_pred), axis=1)

def RMSE(y, y_pred):
  return np.sqrt(np.mean(np.sum(np.square(y - y_pred), axis=1), axis = 1))
```

```
from prettytable import PrettyTable

def generate_table(metrics, metric_values, Exp_names):
    # Print tabular results in the console, in a pretty way
    print('\n')

    tb = PrettyTable()
    ind = 0

    for exp_name in Exp_names:

        tb.field_names = ['Method/Model'] + metrics

        tb_row = []
        tb_row.append(exp_name)

        for metric in metric_values:
            m_mean = np.mean(metric[ind])
            m_std = np.std(metric[ind])
            tb_row.append('{:.3f}'.format(m_mean) + ' (' + '{:.3f}'.format(m_std) + ')')

        tb.add_row(tb_row)
        ind += 1

    print(tb)
```

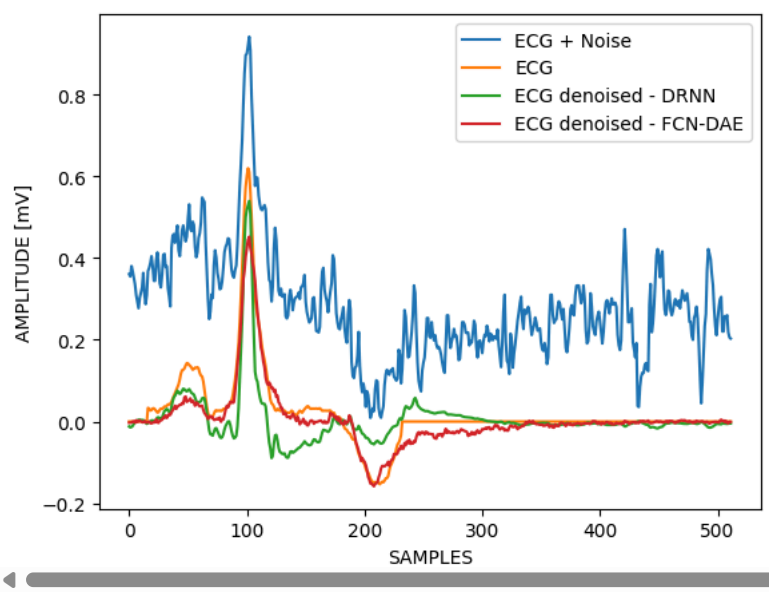
```
# Load Results DRNN
with open('test_results_' + dl_experiments[0] + '.pkl', 'rb') as input:
    test_DRNN = pickle.load(input)

# Load Results FCN_DAE
with open('test_results_' + dl_experiments[1] + '.pkl', 'rb') as input:
    test_FCN_DAE = pickle.load(input)



####### Calculate Metrics #######

print('Calculating metrics ...')

# DL Metrics

# Exp FCN-DAE

[X_test, y_test, y_pred] = test_DRNN

SSD_values_DL_DRNN = SSD(y_test, y_pred)

MAD_values_DL_DRNN = MAD(y_test, y_pred)

RMSE_values_DL_DRNN = RMSE(y_test, y_pred)

# Exp FCN-DAE

[X_test, y_test, y_pred] = test_FCN_DAE
```

```
SSD_values_DL_FCN_DAE = SSD(y_test, y_pred)

MAD_values_DL_FCN_DAE = MAD(y_test, y_pred)

RMSE_values_DL_FCN_DAE = RMSE(y_test, y_pred)
SSD_all = [SSD_values_DL_DRNN,
           SSD_values_DL_FCN_DAE,

           ]

MAD_all = [
           MAD_values_DL_DRNN,
           MAD_values_DL_FCN_DAE,

           ]

RMSE_all = [
            RMSE_values_DL_DRNN,
            RMSE_values_DL_FCN_DAE,
            ]

metrics = ['SSD', 'MAD', 'RMSE']
metric_values = [SSD_all, MAD_all, RMSE_all]

# Metrics table
generate_table(metrics, metric_values, dl_experiments)
```

```
---------------------------------------------------------------------------
NameError                                 Traceback (most recent call last)
<ipython-input-4-bb14c3180a00> in <cell line: 2>()
      1 # Load Results DRNN
----> 2 with open('test_results_' + dl_experiments[0] + '.pkl', 'rb') as input:
      3     test_DRNN = pickle.load(input)
      4
      5 # Load Results FCN_DAE

NameError: name 'dl_experiments' is not defined
```

```
[X_test_1, y_test_1, y_pred_1] = test_DRNN
[X_test_2, y_test_2, y_pred_2] = test_FCN_DAE
```

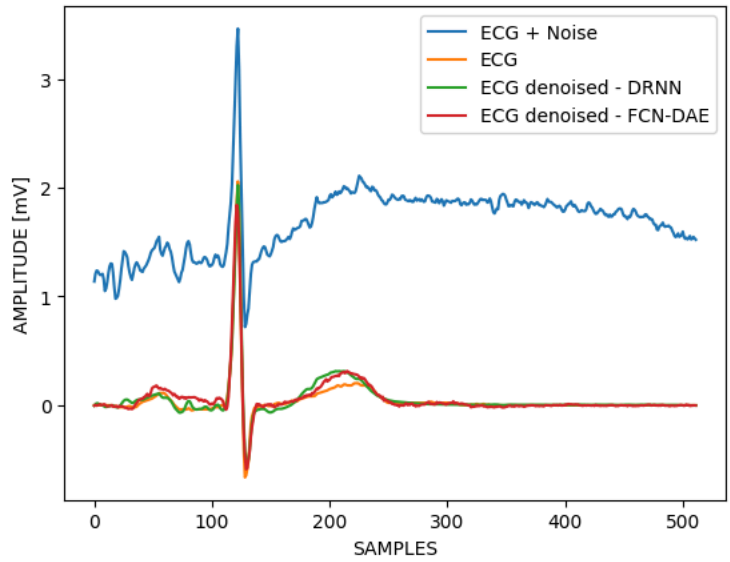
```
plt.plot(X_test_1[3390], label="ECG + Noise")
plt.plot(y_test_1[3390], label="ECG")
plt.plot(y_pred_1[3390], label="ECG denoised - DRNN")
plt.plot(y_pred_2[3390], label="ECG denoised - FCN-DAE")
plt.xlabel("SAMPLES")
plt.ylabel("AMPLITUDE [mV]")
plt.legend()
plt.show()
```



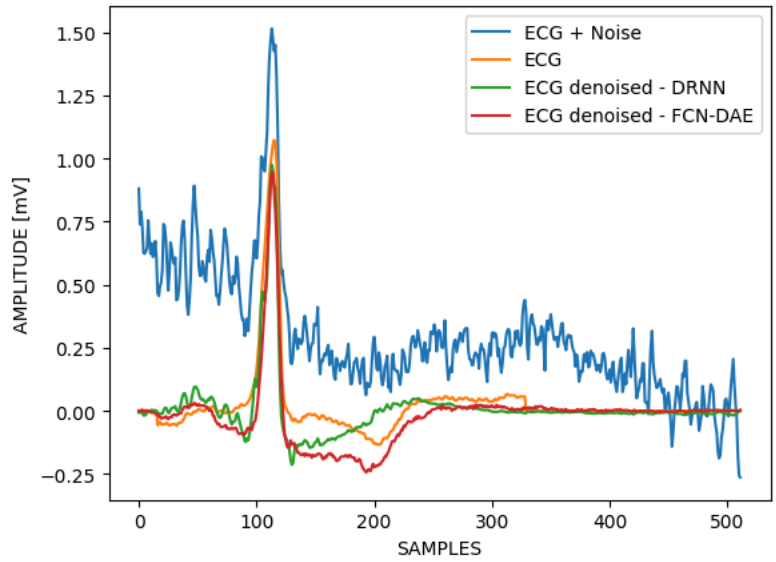

```
for x in np.random.randint(13000, size=50):
  print(x)
  plt.plot(X_test_1[x], label="ECG + Noise")
  plt.plot(y_test_1[x], label="ECG")
```

```
    plt.plot(y_pred_1[x], label="ECG denoised - DRNN")
    plt.plot(y_pred_2[x], label="ECG denoised - FCN-DAE")
    plt.xlabel("SAMPLES")
    plt.ylabel("AMPLITUDE [mV]")
    plt.legend()
    plt.show()
```

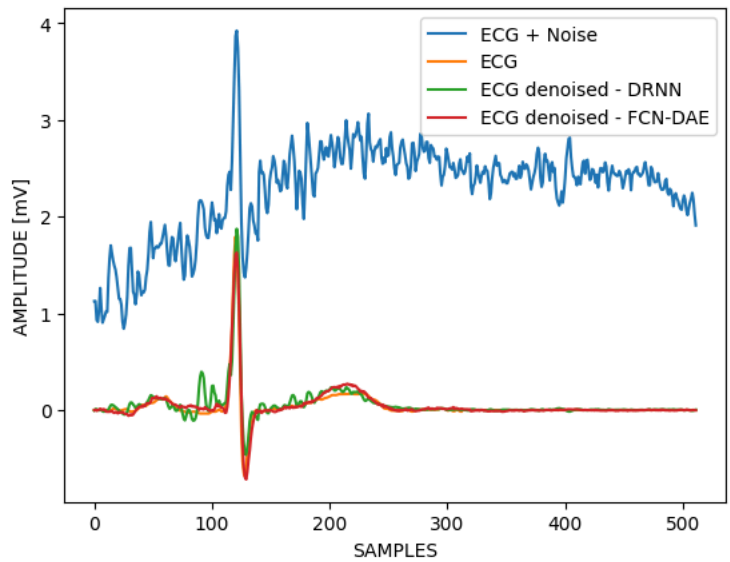
12293



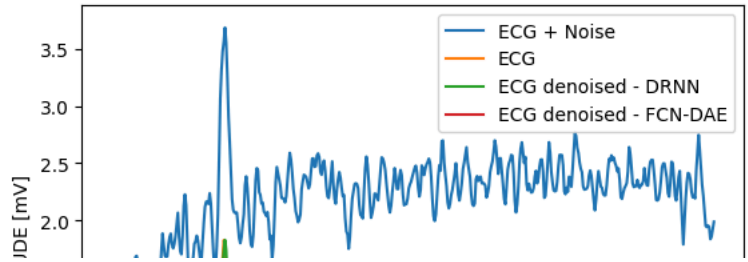
5868

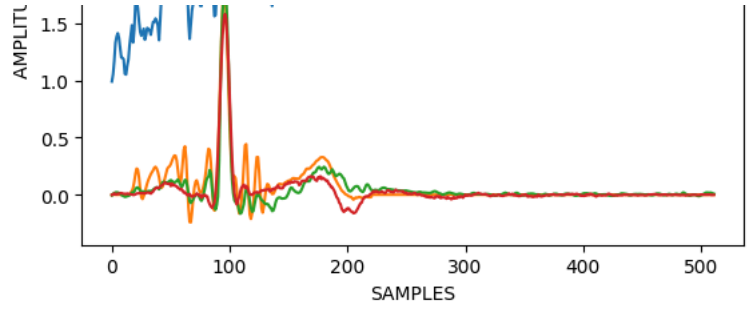


12305

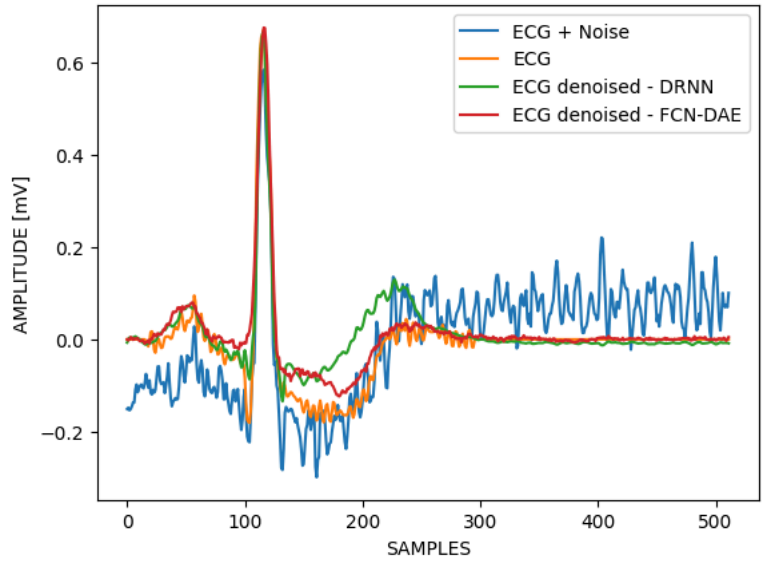


1777

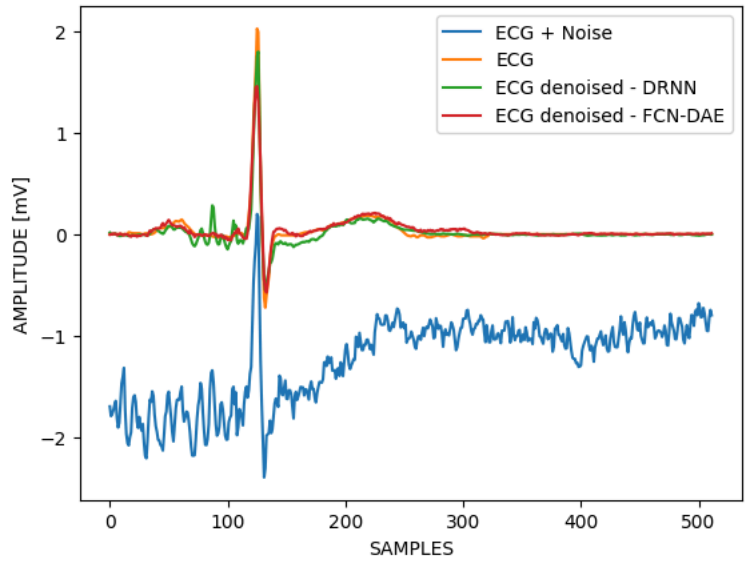




5327



11848



10827