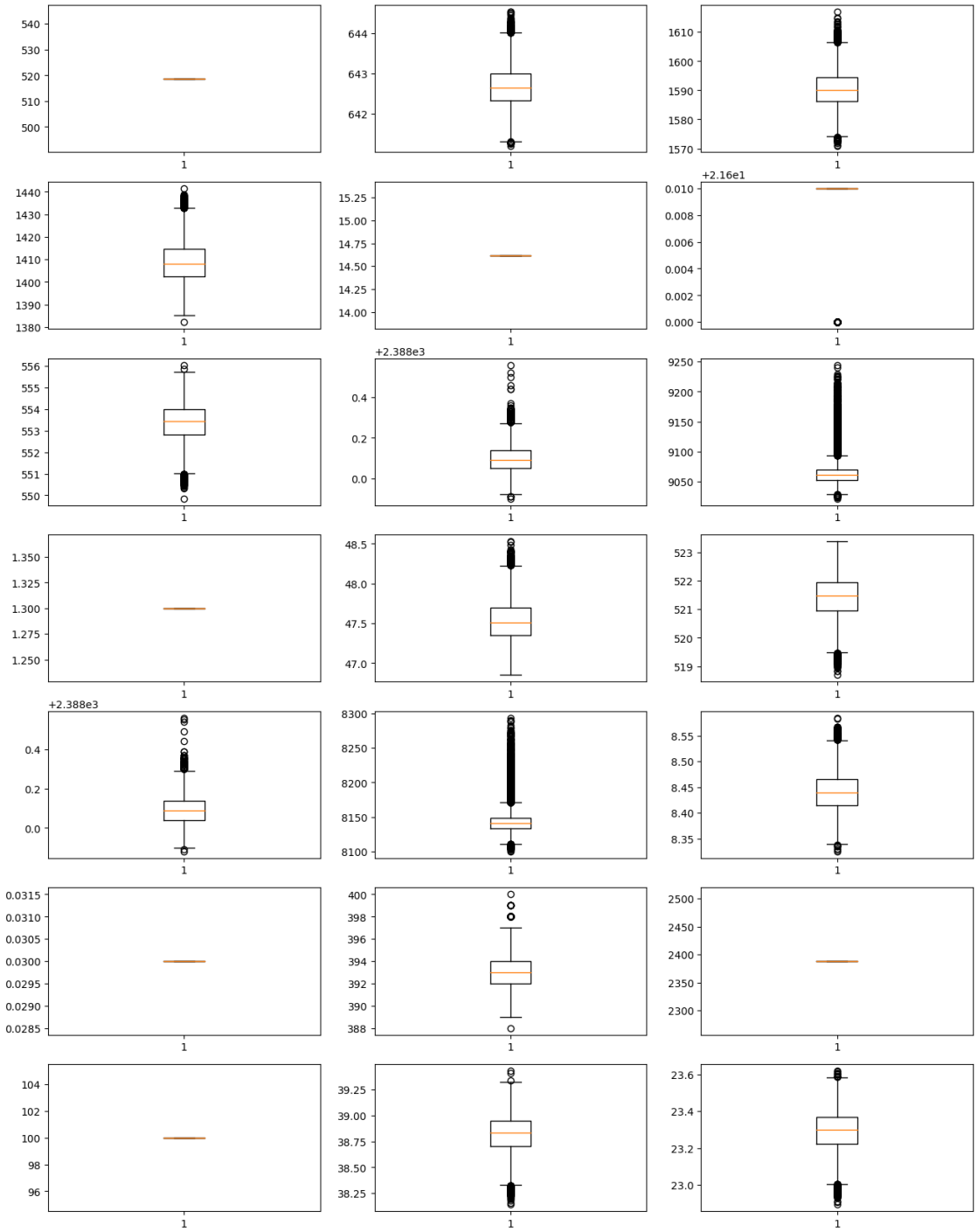
CMAPSS_FD001_Conv+LSTM

May 8, 2024

[1]:
```
import tensorflow as tf
from tensorflow.keras import layers, models
from tensorflow.keras.models import Sequential
import keras

import numpy as np
import pandas as pd
import sklearn
from sklearn.model_selection import train_test_split

from sklearn.preprocessing import MinMaxScaler
from sklearn.metrics import mean_squared_error
import matplotlib.pyplot as plt

np.random.seed(100)
```

1 Data Preprocessing

[2]:
```
train_data = pd.read_csv("train_FD001.txt", sep= "\s+", header = None)
plt.figure(figsize = (16, 21))
for i in range(21):
    temp_data = train_data.iloc[:,i+5]
    plt.subplot(7,3,i+1)
    plt.boxplot(temp_data)
plt.show()
```



[3]:
```
def process_targets(data_length, early_rul = None):
    if early_rul == None:
        return np.arange(data_length-1, -1, -1)
    else:
```

```
        early_rul_duration = data_length - early_rul
        if early_rul_duration <= 0:
            return np.arange(data_length-1, -1, -1)
        else:
            return np.append(early_rul*np.ones(shape = (early_rul_duration,)),␣
↪np.arange(early_rul-1, -1, -1))
```

[4]:
```
def process_input_data_with_targets(input_data, target_data = None,␣
↪window_length = 1, shift = 1):
    num_batches = int(np.floor((len(input_data) - window_length)/shift)) + 1
    num_features = input_data.shape[1]
    output_data = np.repeat(np.nan, repeats = num_batches * window_length *␣
↪num_features).reshape(num_batches, window_length,
                                                                          ␣
↪                   num_features)
    if target_data is None:
        for batch in range(num_batches):
            output_data[batch,:,:] = input_data[(0+shift*batch):
↪(0+shift*batch+window_length),:]
        return output_data
    else:
        output_targets = np.repeat(np.nan, repeats = num_batches)
        for batch in range(num_batches):
            output_data[batch,:,:] = input_data[(0+shift*batch):
↪(0+shift*batch+window_length),:]
            output_targets[batch] = target_data[(shift*batch +␣
↪(window_length-1))]
        return output_data, output_targets
```

[5]:
```
def process_test_data(test_data_for_an_engine, window_length, shift,␣
↪num_test_windows = 1):
    max_num_test_batches = int(np.floor((len(test_data_for_an_engine) -␣
↪window_length)/shift)) + 1
    if max_num_test_batches < num_test_windows:
        required_len = (max_num_test_batches -1)* shift + window_length
        batched_test_data_for_an_engine =␣
↪process_input_data_with_targets(test_data_for_an_engine[-required_len:, :],
                                                                          ␣
↪target_data = None,
                                                                          ␣
↪window_length = window_length, shift = shift)
        return batched_test_data_for_an_engine, max_num_test_batches
    else:
        required_len = (num_test_windows - 1) * shift + window_length
        batched_test_data_for_an_engine =␣
↪process_input_data_with_targets(test_data_for_an_engine[-required_len:, :],
```

```
↪target_data = None,
↪window_length = window_length, shift = shift)
        return batched_test_data_for_an_engine, num_test_windows
```

[6]:

```
test_data = pd.read_csv("test_FD001.txt", sep = "\s+", header = None)
true_rul = pd.read_csv("RUL_FD001.txt", sep = '\s+', header = None)

window_length = 30
shift = 1
early_rul = 130
processed_train_data = []
processed_train_targets = []
num_test_windows = 5
processed_test_data = []
num_test_windows_list = []

columns_to_be_dropped = [0,1,2,3,4,5,9,10,14,20,22,23]

train_data_first_column = train_data[0]
test_data_first_column = test_data[0]

scaler = MinMaxScaler(feature_range = (-1,1))
train_data = scaler.fit_transform(train_data.drop(columns =
↪columns_to_be_dropped))
test_data = scaler.transform(test_data.drop(columns = columns_to_be_dropped))

train_data = pd.DataFrame(data = np.c_[train_data_first_column, train_data])
test_data = pd.DataFrame(data = np.c_[test_data_first_column, test_data])

num_train_machines = len(train_data[0].unique())
num_test_machines = len(test_data[0].unique())

for i in np.arange(1, num_train_machines + 1):
    temp_train_data = train_data[train_data[0] == i].drop(columns = [0]).values

    if (len(temp_train_data) < window_length):
        print("Train engine {} doesn't have enough data for window_length of
↪{}".format(i, window_length))
        raise AssertionError("Window length is larger than number of data
↪points for some engines. "
                             "Try decreasing window length.")

    temp_train_targets = process_targets(data_length = temp_train_data.
↪shape[0], early_rul = early_rul)
```

```
    data_for_a_machine, targets_for_a_machine =␣
 ↪process_input_data_with_targets(temp_train_data, temp_train_targets,
                                                                    ␣
 ↪window_length = window_length, shift = shift)

    processed_train_data.append(data_for_a_machine)
    processed_train_targets.append(targets_for_a_machine)

processed_train_data = np.concatenate(processed_train_data)
processed_train_targets = np.concatenate(processed_train_targets)

for i in np.arange(1, num_test_machines + 1):
    temp_test_data = test_data[test_data[0] == i].drop(columns = [0]).values

    if (len(temp_test_data) < window_length):
        print("Test engine {} doesn't have enough data for window_length of {}".
 ↪format(i, window_length))
        raise AssertionError("Window length is larger than number of data␣
 ↪points for some engines. "
                             "Try decreasing window length.")

    test_data_for_an_engine, num_windows = process_test_data(temp_test_data,␣
 ↪window_length = window_length, shift = shift,
                                                          num_test_windows =␣
 ↪num_test_windows)

    processed_test_data.append(test_data_for_an_engine)
    num_test_windows_list.append(num_windows)

processed_test_data = np.concatenate(processed_test_data)
true_rul = true_rul[0].values

index = np.random.permutation(len(processed_train_targets))
processed_train_data, processed_train_targets = processed_train_data[index],␣
 ↪processed_train_targets[index]

print("Processed trianing data shape: ", processed_train_data.shape)
print("Processed training ruls shape: ", processed_train_targets.shape)
print("Processed test data shape: ", processed_test_data.shape)
print("True RUL shape: ", true_rul.shape)
```

```
Processed trianing data shape:  (17731, 30, 14)
Processed training ruls shape:  (17731,)
Processed test data shape:  (497, 30, 14)
True RUL shape:  (100,)
```

[7]:
```
processed_train_data, processed_val_data, processed_train_targets,␣
↪processed_val_targets = train_test_split(processed_train_data,
                                                                    ␣
↪                              processed_train_targets,
                                                                    ␣
↪                              test_size = 0.2,
                                                                    ␣
↪                              random_state = 83)
print("Processed train data shape: ", processed_train_data.shape)
print("Processed validation data shape: ", processed_val_data.shape)
print("Processed train targets shape: ", processed_train_targets.shape)
print("Processed validation targets shape: ", processed_val_targets.shape)
```

```
Processed train data shape:  (14184, 30, 14)
Processed validation data shape:  (3547, 30, 14)
Processed train targets shape:  (14184,)
Processed validation targets shape:  (3547,)
```

2 Conv+LSTM model

[8]:
```
runs = 5

test_rmse = np.zeros(runs)

for i in range(runs):

  model = models.Sequential([
      layers.Conv1D(18, kernel_size = 2, strides = 1, activation = 'relu',␣
↪input_shape = (window_length, processed_train_data.shape[2])),
      layers.MaxPool1D(2, strides = 2),
      layers.Conv1D(36, kernel_size = 2, strides = 1, activation = 'relu'),
      layers.MaxPool1D(2, strides = 2),
      layers.Dense(window_length*processed_train_data.shape[2], activation =␣
↪'relu'),
      layers.Dropout(0.2),
      layers.LSTM(processed_train_data.shape[2]*3, return_sequences = True),
      layers.LSTM(processed_train_data.shape[2]*3),
      layers.Dense(50, activation = 'relu'),
      layers.Dropout(0.5),
      layers.Dense(1)
  ])

  model.compile(optimizer='adam',
                loss='mean_squared_error',
                metrics=[keras.metrics.RootMeanSquaredError()])
```

```
  history = model.fit(processed_train_data, processed_train_targets, epochs =␣
 ↪10,
                      validation_data = (processed_val_data,␣
 ↪processed_val_targets),
                      batch_size = 32, verbose = False)

  rul_pred = model.predict(processed_test_data).reshape(-1)
  preds_for_each_engine = np.split(rul_pred, np.cumsum(num_test_windows_list)[:
 ↪-1])

  indices_of_last_examples = np.cumsum(num_test_windows_list) - 1
  preds_for_last_example = np.
 ↪concatenate(preds_for_each_engine)[indices_of_last_examples]

  RMSE_new = np.sqrt(mean_squared_error(true_rul, preds_for_last_example))

  test_rmse[i] = RMSE_new

  print('RMSE in trial', i+1, ':', test_rmse[i])

print(f'Avg test RMSE over 5 iterations : {test_rmse.mean()}')
```

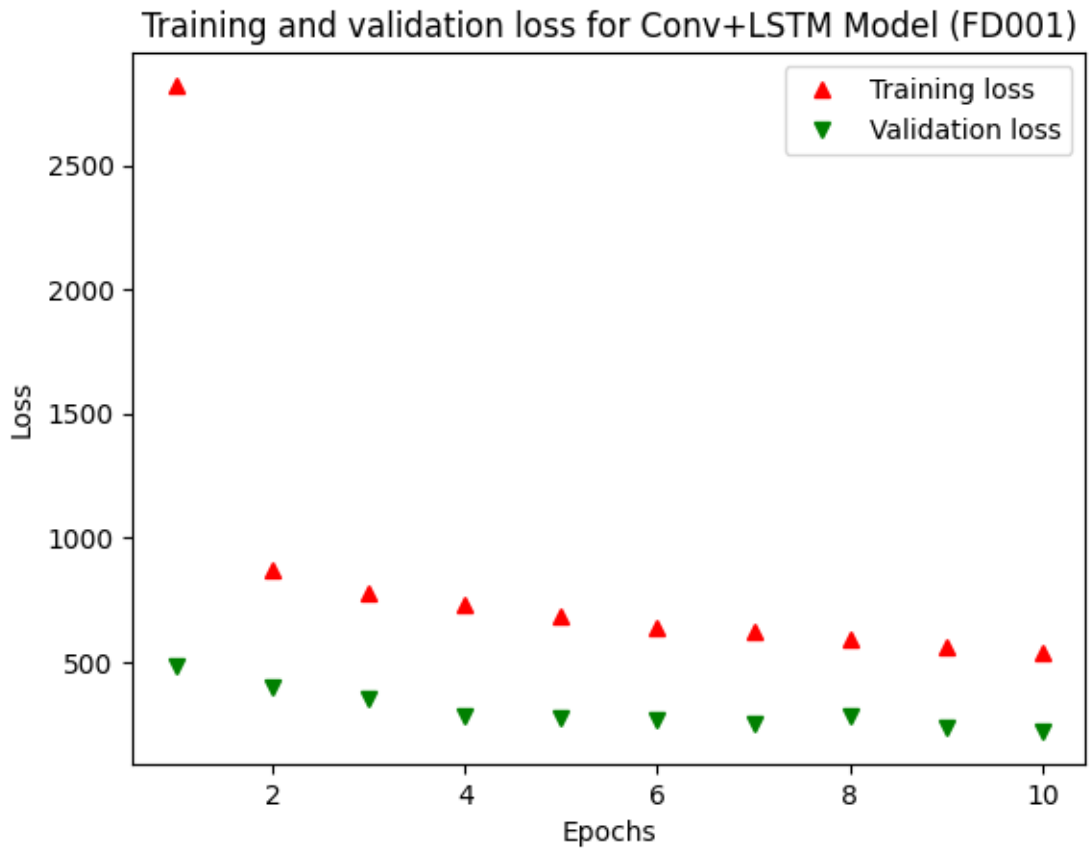
```
16/16 [==============================] - 1s 5ms/step
RMSE in trial 1 : 15.034169462022797
16/16 [==============================] - 1s 8ms/step
RMSE in trial 2 : 16.674193517464293
16/16 [==============================] - 1s 5ms/step
RMSE in trial 3 : 16.38683431593682
16/16 [==============================] - 1s 5ms/step
RMSE in trial 4 : 17.505605233802033
16/16 [==============================] - 1s 5ms/step
RMSE in trial 5 : 15.370842265530385
Avg test RMSE over 5 iterations : 16.194328958951267
```

[9]:
```
model.summary()
```

```
Model: "sequential_4"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv1d_8 (Conv1D)           (None, 29, 18)            522

 max_pooling1d_8 (MaxPoolin  (None, 14, 18)            0
 g1D)

 conv1d_9 (Conv1D)           (None, 13, 36)            1332

 max_pooling1d_9 (MaxPoolin  (None, 6, 36)             0
```

```
g1D)

dense_12 (Dense)            (None, 6, 420)            15540

dropout_8 (Dropout)         (None, 6, 420)            0

lstm_8 (LSTM)               (None, 6, 42)             77784

lstm_9 (LSTM)               (None, 42)                14280

dense_13 (Dense)            (None, 50)                2150

dropout_9 (Dropout)         (None, 50)                0

dense_14 (Dense)            (None, 1)                 51

=================================================================
Total params: 111659 (436.17 KB)
Trainable params: 111659 (436.17 KB)
Non-trainable params: 0 (0.00 Byte)
_________________________________________________________________
```

[10]:
```
loss = history.history['loss']
val_loss = history.history['val_loss']

epochs = range(1, len(loss) + 1)

plt.plot(epochs, loss, 'r^', label='Training loss')
plt.plot(epochs, val_loss, 'gv', label='Validation loss')
plt.title('Training and validation loss for Conv+LSTM Model (FD001)')
plt.xlabel('Epochs')
plt.ylabel('Loss')
plt.legend()

plt.show()
```



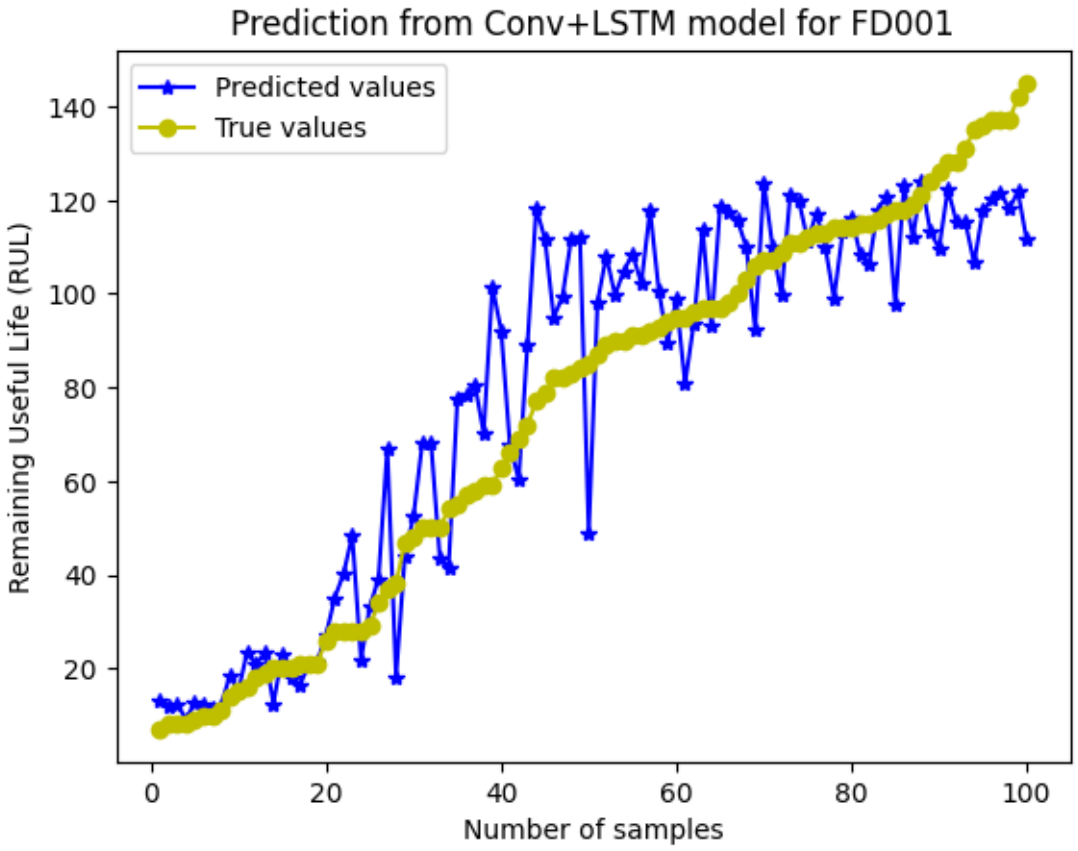
[11]:
```
def compute_s_score(rul_true, rul_pred):
    diff = rul_pred - rul_true
    return np.sum(np.where(diff < 0, np.exp(-diff/13)-1, np.exp(diff/10)-1))
```

[12]:
```
s_score = compute_s_score(true_rul, preds_for_last_example)
print("S-score: ", s_score)
```

```
S-score:  440.4041545632073
```

[13]:
```
y_pred_series = pd.Series(preds_for_last_example.flatten())
y_test_series = pd.Series(true_rul.flatten())

df = pd.DataFrame({'y_pred_fd001': y_pred_series, 'y_test_fd001':␣
 ↪y_test_series})

df = df.sort_values('y_test_fd001')

number_of_sample = range(1, len(true_rul) + 1)

plt.plot(number_of_sample, df['y_pred_fd001'], 'b*-', label='Predicted values')
```

```
plt.plot(number_of_sample, df['y_test_fd001'], 'yo-', label='True values')
plt.title('Prediction from Conv+LSTM model for FD001')
plt.xlabel('Number of samples')
plt.ylabel('Remaining Useful Life (RUL)')
plt.legend()

plt.show()
```



[13]: