Problem_3

April 19, 2024

1 Problem #3

1.1 Data Ingest and Formatting

[ ]:
```
# Common Imports
import csv
import pathlib
import random
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
from tqdm.auto import tqdm
from prettytable import PrettyTable

import tensorflow as tf
import numpy as np
from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input
from tensorflow.keras.layers import Dense
from tensorflow.keras.layers import Activation
from tensorflow.keras.metrics import R2Score
from tensorflow.keras.metrics import Accuracy
from tensorflow.keras.metrics import RootMeanSquaredError
from tensorflow.keras.callbacks import History
from tensorflow.keras.callbacks import EarlyStopping
from tensorflow.keras import ops
from tensorflow.keras import layers
import tensorflow.keras.backend as K

# Ensure the plot output directory exists
pathlib.Path('./out').mkdir(parents=True, exist_ok=True)

# Import the subject data as dataframes
training_data = []
for i in range(1, 9):
    training_data.append({
        "in": pd.read_csv(f'./data/sub_{i}_input.csv'),
        "out": pd.read_csv(f'./data/sub_{i}_output.csv')
```

```
    })
test_data = {
    "in": pd.read_csv('./data/sub_9_input.csv'),
    "out": pd.read_csv('./data/sub_9_output.csv')
}
exam_data = pd.read_csv('./data/sub_10_input.csv')

# Array of field names
input_fields = [
    'q_hip_right',
    'q_knee_right',
    'q_hip_left',
    'q_knee_left',
    'dq_hip_right',
    'dq_knee_right',
    'dq_hip_left',
    'dq_knee_left',
    'u_hip_right',
    'u_knee_right',
    'u_hip_left',
    'u_knee_left',
    'gyro_right_thigh_x',
    'gyro_right_thigh_y',
    'gyro_right_thigh_z',
    'gyro_left_thigh_x',
    'gyro_left_thigh_y',
    'gyro_left_thigh_z',
    'acc_right_thigh_x',
    'acc_right_thigh_y',
    'acc_right_thigh_z',
    'acc_left_thigh_x',
    'acc_left_thigh_y',
    'acc_left_thigh_z',
    'acc_gu_right_foot_x',
    'acc_gu_right_foot_y',
    'acc_gu_right_foot_z',
    'acc_gu_left_foot_x',
    'acc_gu_left_foot_y',
    'acc_gu_left_foot_z',
    'acc_gu_right_shank_x',
    'acc_gu_right_shank_y',
    'acc_gu_right_shank_z',
    'acc_gu_left_shank_x',
    'acc_gu_left_shank_y',
    'acc_gu_left_shank_z',
    'gyro_gu_right_foot_x',
    'gyro_gu_right_foot_y',
```

```
    'gyro_gu_right_foot_z',
    'gyro_gu_left_foot_x',
    'gyro_gu_left_foot_y',
    'gyro_gu_left_foot_z',
    'gyro_gu_right_shank_x',
    'gyro_gu_right_shank_y',
    'gyro_gu_right_shank_z',
    'gyro_gu_left_shank_x',
    'gyro_gu_left_shank_y',
    'gyro_gu_left_shank_z',
    'sf_right',
    'sf_left'
]
output_fields = [
    'grf_right_y',
    'grf_right_z',
    'grf_left_y',
    'grf_left_z',
]
```

1.2 Machine Learning Model

1.2.1 Training

[ ]:
```
# Create the Model
inputs = Input(shape=(len(input_fields),))
x = layers.Dense(len(input_fields)*2, activation='sigmoid')(inputs)
x = layers.Dense(len(input_fields)*2, activation='sigmoid')(x)
# x = layers.Dense(len(input_fields)*2, activation='sigmoid')(x)
outputs = layers.Dense(len(output_fields), activation='linear')(x)
model = Model(inputs=inputs, outputs=outputs, name='WalkieBoi')
model.summary()
model.build(input_shape=(None, len(input_fields)))

def root_mean_squared_error(y_true, y_pred):
        return K.sqrt(K.mean(K.square(y_pred - y_true)))

model.compile(optimizer='rmsprop',
              loss = root_mean_squared_error,
              metrics=[RootMeanSquaredError(), R2Score()])

# Train the Model
X = np.empty((0,len(input_fields)))
Y = np.empty((0,len(output_fields)))
for i in range(1, 9):
    X = np.concatenate((X, training_data[i-1]['in'].to_numpy()), axis=0)
    Y = np.concatenate((Y, training_data[i-1]['out'].to_numpy()), axis=0)
```

```
history = model.fit(x=X, y=Y, batch_size=50, shuffle='batch', epochs=100,
                    validation_data=(test_data['in'], test_data['out']),
                    callbacks=[History(),
                               EarlyStopping(monitor='val_loss',
                                             patience=5,
                                             restore_best_weights=True)])
history = pd.DataFrame(history.history)
```

Model: "WalkieBoi"

Layer (type)	Output Shape	Param #
input_layer (InputLayer)	(None, 50)	0
dense (Dense)	(None, 100)	5,100
dense_1 (Dense)	(None, 100)	10,100
dense_2 (Dense)	(None, 4)	404

Total params: 15,604 (60.95 KB)

Trainable params: 15,604 (60.95 KB)

Non-trainable params: 0 (0.00 B)

```
Epoch 1/100
3373/3373            6s 2ms/step -
loss: 0.0987 - r2_score: -3.6498 - root_mean_squared_error: 0.1107 - val_loss:
0.0928 - val_r2_score: 0.4450 - val_root_mean_squared_error: 0.1028
Epoch 2/100
3373/3373            6s 2ms/step -
loss: 0.0519 - r2_score: 0.6853 - root_mean_squared_error: 0.0593 - val_loss:
0.0881 - val_r2_score: 0.6554 - val_root_mean_squared_error: 0.0976
Epoch 3/100
3373/3373            6s 2ms/step -
loss: 0.0418 - r2_score: 0.8476 - root_mean_squared_error: 0.0512 - val_loss:
0.0826 - val_r2_score: 0.6590 - val_root_mean_squared_error: 0.0950
Epoch 4/100
3373/3373            4s 1ms/step -
loss: 0.0384 - r2_score: 0.8656 - root_mean_squared_error: 0.0480 - val_loss:
0.0804 - val_r2_score: 0.6985 - val_root_mean_squared_error: 0.0936
```

```
Epoch 5/100
3373/3373            8s 2ms/step -
loss: 0.0366 - r2_score: 0.8835 - root_mean_squared_error: 0.0460 - val_loss:
0.0777 - val_r2_score: 0.7104 - val_root_mean_squared_error: 0.0913
Epoch 6/100
3373/3373            4s 1ms/step -
loss: 0.0353 - r2_score: 0.8881 - root_mean_squared_error: 0.0444 - val_loss:
0.0770 - val_r2_score: 0.7192 - val_root_mean_squared_error: 0.0901
Epoch 7/100
3373/3373            4s 1ms/step -
loss: 0.0345 - r2_score: 0.8946 - root_mean_squared_error: 0.0436 - val_loss:
0.0771 - val_r2_score: 0.7227 - val_root_mean_squared_error: 0.0905
Epoch 8/100
3373/3373            4s 1ms/step -
loss: 0.0339 - r2_score: 0.8963 - root_mean_squared_error: 0.0427 - val_loss:
0.0755 - val_r2_score: 0.7562 - val_root_mean_squared_error: 0.0890
Epoch 9/100
3373/3373            7s 2ms/step -
loss: 0.0338 - r2_score: 0.8942 - root_mean_squared_error: 0.0426 - val_loss:
0.0735 - val_r2_score: 0.7632 - val_root_mean_squared_error: 0.0864
Epoch 10/100
3373/3373            6s 2ms/step -
loss: 0.0331 - r2_score: 0.8993 - root_mean_squared_error: 0.0415 - val_loss:
0.0728 - val_r2_score: 0.7555 - val_root_mean_squared_error: 0.0857
Epoch 11/100
3373/3373            7s 2ms/step -
loss: 0.0328 - r2_score: 0.9000 - root_mean_squared_error: 0.0409 - val_loss:
0.0718 - val_r2_score: 0.7644 - val_root_mean_squared_error: 0.0846
Epoch 12/100
3373/3373            5s 1ms/step -
loss: 0.0321 - r2_score: 0.9031 - root_mean_squared_error: 0.0399 - val_loss:
0.0713 - val_r2_score: 0.7916 - val_root_mean_squared_error: 0.0848
Epoch 13/100
3373/3373            7s 2ms/step -
loss: 0.0318 - r2_score: 0.9049 - root_mean_squared_error: 0.0396 - val_loss:
0.0709 - val_r2_score: 0.7807 - val_root_mean_squared_error: 0.0835
Epoch 14/100
3373/3373            7s 2ms/step -
loss: 0.0317 - r2_score: 0.9061 - root_mean_squared_error: 0.0393 - val_loss:
0.0705 - val_r2_score: 0.7894 - val_root_mean_squared_error: 0.0828
Epoch 15/100
3373/3373            10s 2ms/step -
loss: 0.0314 - r2_score: 0.9076 - root_mean_squared_error: 0.0391 - val_loss:
0.0688 - val_r2_score: 0.8006 - val_root_mean_squared_error: 0.0803
Epoch 16/100
3373/3373            6s 2ms/step -
loss: 0.0310 - r2_score: 0.9066 - root_mean_squared_error: 0.0382 - val_loss:
0.0680 - val_r2_score: 0.8030 - val_root_mean_squared_error: 0.0795
```

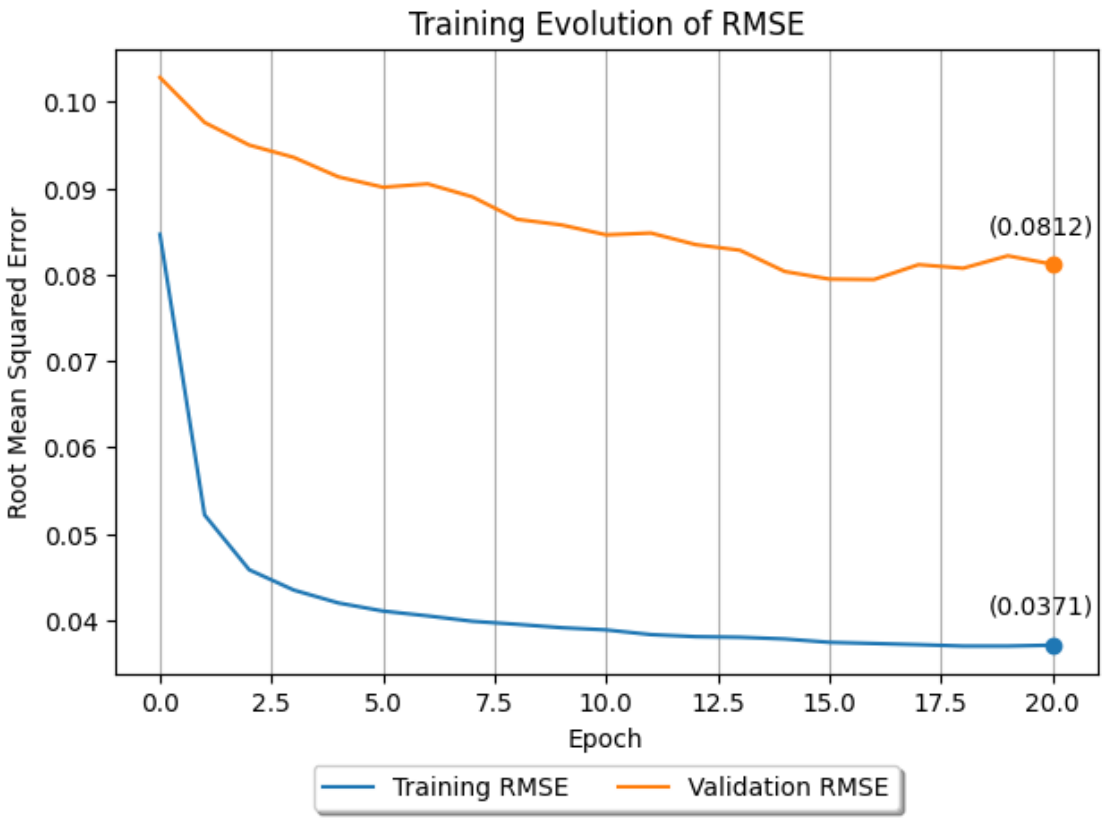
```
Epoch 17/100
3373/3373             10s 2ms/step -
loss: 0.0308 - r2_score: 0.9097 - root_mean_squared_error: 0.0380 - val_loss:
0.0682 - val_r2_score: 0.8014 - val_root_mean_squared_error: 0.0794
Epoch 18/100
3373/3373             8s 2ms/step -
loss: 0.0306 - r2_score: 0.9117 - root_mean_squared_error: 0.0378 - val_loss:
0.0697 - val_r2_score: 0.7944 - val_root_mean_squared_error: 0.0811
Epoch 19/100
3373/3373             6s 2ms/step -
loss: 0.0306 - r2_score: 0.9114 - root_mean_squared_error: 0.0377 - val_loss:
0.0698 - val_r2_score: 0.8062 - val_root_mean_squared_error: 0.0807
Epoch 20/100
3373/3373             6s 2ms/step -
loss: 0.0304 - r2_score: 0.9129 - root_mean_squared_error: 0.0373 - val_loss:
0.0709 - val_r2_score: 0.8119 - val_root_mean_squared_error: 0.0822
Epoch 21/100
3373/3373             7s 2ms/step -
loss: 0.0307 - r2_score: 0.9127 - root_mean_squared_error: 0.0378 - val_loss:
0.0704 - val_r2_score: 0.8081 - val_root_mean_squared_error: 0.0812
```

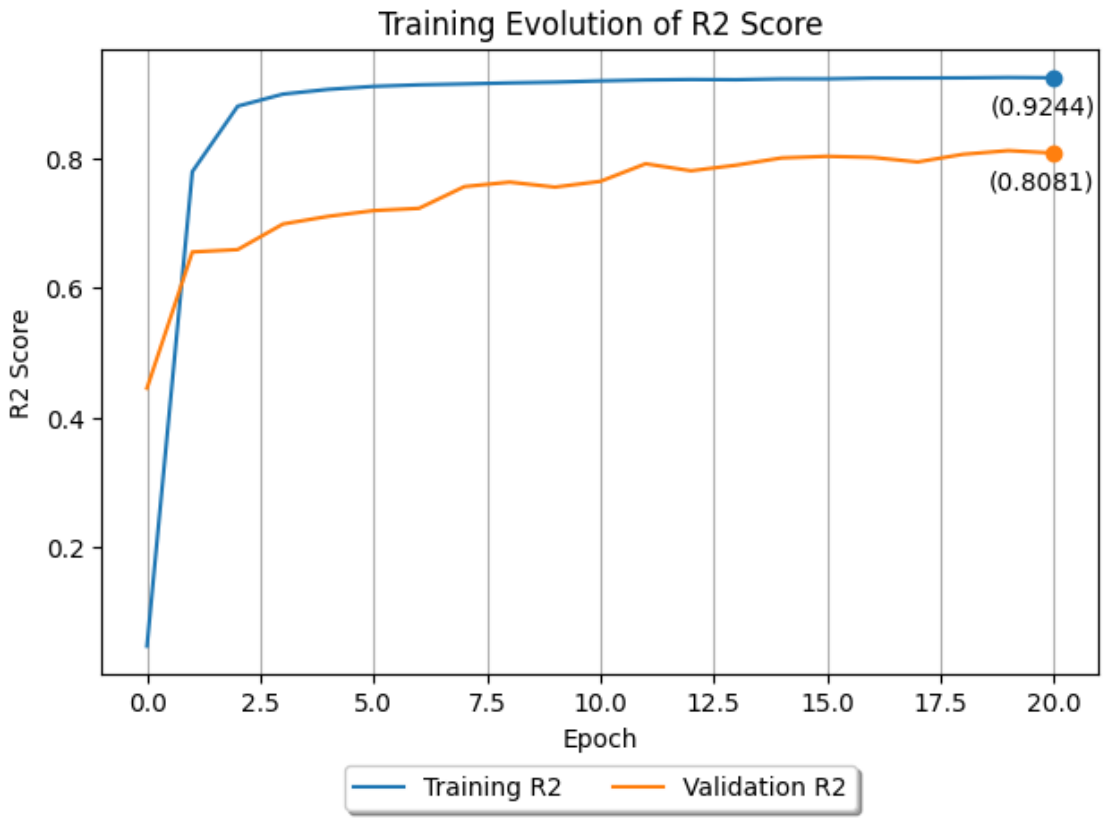
1.2.2 Training Results

[ ]:
```python
# Plot the RSME Training History
fig, ax = plt.subplots()
ax.plot(history['root_mean_squared_error'], label='Training RMSE')
ax.plot(history['val_root_mean_squared_error'], label='Validation RMSE')
ax.plot(len(history['root_mean_squared_error'])-1,
        history['root_mean_squared_error'].iloc[-1],
        'o', label='', color='tab:blue')
ax.text(len(history['root_mean_squared_error'])-1.25,
        history['root_mean_squared_error'].iloc[-1]+0.003,
        f'({history["root_mean_squared_error"].iloc[-1]:.4f})',
        fontsize=10, ha='center', va='bottom')
ax.plot(len(history['val_root_mean_squared_error'])-1,
        history['val_root_mean_squared_error'].iloc[-1],
        'o', label='', color='tab:orange')
ax.text(len(history['val_root_mean_squared_error'])-1.25,
        history['val_root_mean_squared_error'].iloc[-1]+0.003,
        f'({history["val_root_mean_squared_error"].iloc[-1]:.4f})',
        fontsize=10, ha='center', va='bottom')
ax.set_title('Training Evolution of RMSE')
ax.set_xlabel('Epoch')
ax.set_ylabel('Root Mean Squared Error')
ax.xaxis.grid()
ax.legend(loc='upper center', bbox_to_anchor=(0.5, -0.125),
          fancybox=True, shadow=True, ncol=2)
```

```
plt.tight_layout()
plt.savefig('./out/training_history_rmse.png')
plt.show()

# Plot the R2 Score Training History
fig, ax = plt.subplots()
ax.plot(history['r2_score'], label='Training R2')
ax.plot(history['val_r2_score'], label='Validation R2')
ax.plot(len(history['r2_score'])-1,
        history['r2_score'].iloc[-1],
        'o', label='', color='tab:blue')
ax.text(len(history['r2_score'])-1.25,
        history['r2_score'].iloc[-1]-0.065,
        f'({history["r2_score"].iloc[-1]:.4f})',
        fontsize=10, ha='center', va='bottom')
ax.plot(len(history['val_r2_score'])-1,
        history['val_r2_score'].iloc[-1],
        'o', label='', color='tab:orange')
ax.text(len(history['val_r2_score'])-1.25,
        history['val_r2_score'].iloc[-1]-0.065,
        f'({history["val_r2_score"].iloc[-1]:.4f})',
        fontsize=10, ha='center', va='bottom')
ax.set_title('Training Evolution of R2 Score')
ax.set_xlabel('Epoch')
ax.set_ylabel('R2 Score')
ax.xaxis.grid()
ax.legend(loc='upper center', bbox_to_anchor=(0.5, -0.125),
          fancybox=True, shadow=True, ncol=2)
plt.tight_layout()
plt.savefig('./out/training_history_r2.png')
plt.show()
```


Training Evolution of RMSE
Root Mean Squared Error
0.10
0.09
0.08
0.07
0.06
0.05
0.04
(0.0812)
(0.0371)
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
Epoch
Training RMSE
Validation RMSE



1.2.3 Prediction

[ ]:
```
# Predict the output for subject 10
predictions = model.predict(test_data['in'], batch_size=1)
predictions = pd.DataFrame(predictions, columns=output_fields)

# Save the predictions to a CSV file
predictions.to_csv('./out/sub_10_output.csv', index=False, float_format='%.16f')
```

```
20000/20000              16s
802us/step
```

[ ]:
```
# Plot the Predictions
fig, axs = plt.subplots(2, 1, figsize=(24, 12))
axs[0].plot(predictions['grf_right_y'], label='GRF Right Y')
axs[0].plot(predictions['grf_left_y'], label='GRF Left Y')
axs[0].set_title('Predicted GRF Y')
axs[0].set_xlabel('Time Step')
axs[0].set_ylabel('Force [N]')
axs[0].legend()
axs[0].xaxis.grid()
```

```
axs[1].plot(predictions['grf_right_z'], label='GRF Right Z')
axs[1].plot(predictions['grf_left_z'], label='GRF Left Z')
axs[1].set_title('Predicted GRF Z')
axs[1].set_xlabel('Time Step')
axs[1].set_ylabel('Force [N]')
axs[1].legend()
axs[1].xaxis.grid()
plt.tight_layout()
plt.savefig('./out/predictions.png')
plt.show()
```