Model_Training_LSTM

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1 Controlador de vuelo para vehículos aéreos no tripulados multi-rotor basado en técnicas de aprendizaje profundo

1.1 Entrenamiento Red LSTM

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1.2 1. Descripción del Dataset

Importar Librerías

[1]:
```
import os
import sys
import random

import pandas as pd
pd.set_option('display.max_columns', None) #Para mostrar todas las columnas
import matplotlib.pyplot as plt

import numpy as np                    # Cómputo Numérico
print(np.__version__)
assert (np.__version__=='1.19.5'), 'Versión incorrecta de numpy, por favor␣
↪instale 1.19.5'
seed = 5
np.random.seed(seed)
np.seterr(divide = 'ignore')
```

```
1.19.5
```

[1]:
```
{'divide': 'warn', 'over': 'warn', 'under': 'ignore', 'invalid': 'warn'}
```

[2]:
```
import keras as kr

import tensorflow as tf
from tensorflow.keras import models, layers
print(tf.__version__)
assert (tf.__version__=='2.5.0'), 'Versión incorrecta de Tensorflow, por favor␣
↪instale 2.5.0'
print("Num GPUs Available: ", len(tf.config.list_physical_devices('GPU')))
```

```
from tensorflow.compat.v1 import ConfigProto
from tensorflow.compat.v1 import InteractiveSession

from sklearn.utils import shuffle
from sklearn.model_selection import train_test_split


from IPython.display import clear_output
```

```
2.5.0
Num GPUs Available:  1
```

[3]:
```
gpus = tf.config.list_physical_devices('GPU')
config = ConfigProto()
if gpus:
    try:
        config.gpu_options.allow_growth = True
        tf.compat.v1.enable_eager_execution()

        os.environ["TF_CPP_MIN_LOG_LEVEL"] = "2"
        # Currently, memory growth needs to be the same across GPUs
        for gpu in gpus:
            tf.config.experimental.set_memory_growth(gpu, True)
        logical_gpus = tf.config.experimental.list_logical_devices('GPU')
        print(len(gpus), "Physical GPUs,", len(logical_gpus), "Logical GPUs")
    except RuntimeError as e:
        # Memory growth must be set before GPUs have been initialized
        print(e)
session = InteractiveSession(config=config)
```

```
1 Physical GPUs, 1 Logical GPUs
```

[4]:
```
import gc #garbage collector
import gc; gc.enable()
```

1.3 Cargar Datos

1.3.1 Leemos el Dataset

[5]:
```
root = '../logs/Datasets/'
dataset_name = 'Dataset_Final'
rootdir = root+dataset_name
if not os.path.exists(rootdir):
    print(f"{rootdir} not exist")
```

[6]:
```
df = pd.read_csv(os.path.join(rootdir, random.choice(os.listdir(rootdir))))
delete_list = ['timestamps',
               'Q1', 'Q2', 'Q3', 'Q4',
               'uvx', 'uvy', 'uvz',
```

```
                'up', 'uq',
                'uwp', 'uwq', 'uwr']
df_list = df.columns.to_list()
rpm_list = [i for i in df_list if ("RPM" in i)]
states_list = [i for i in df_list if not ((i in delete_list) or (i in␣
↪rpm_list))]
Ts = df['timestamps'][1]-df['timestamps'][0]
fs = 1/Ts
```

[7]:
```
dataset = []
for filename in os.listdir(rootdir):
    if not filename.endswith(".csv"):
        continue

    df = pd.read_csv(os.path.join(rootdir, filename))
    df =  df.drop(delete_list, axis=1)
    x = df.drop(rpm_list, axis=1)
    y = df.drop(states_list, axis=1)
    dataset.append([x, y])

df = None
x = None
y= None
```

Normalización de Estados (Entradas) y Acciones (Salidas)

[8]:
```
def Norm(df, df_desc):
    for prop in list(df.columns):
        try:
            # 1 ~ Mean  7 ~ Max  3 ~ Min
            df[prop] = (df[prop]-df_desc[prop]['mean'])/
↪(df_desc[prop]['max']-df_desc[prop]['min'])
        except e:
            print(e)
    return df
```

[9]:
```
norm_data_path = f"{root}/data_description_{dataset_name}.csv"
df_desc = pd.read_csv(norm_data_path, index_col=0)
df_desc
```

[9]:

	x	y	z	p	q	\
count	3.068233e+06	3.068233e+06	3.068233e+06	3.068233e+06	3.068233e+06	
mean	6.352137e-03	3.631930e-03	8.701060e-01	8.113104e-04	7.632901e-04	
std	1.067096e-01	1.015022e-01	7.571069e-01	3.005110e-02	3.288610e-02	
min	-8.166897e-01	-8.176113e-01	2.113373e-04	-4.872289e-01	-4.386099e-01	
25%	-7.023093e-03	-4.566531e-03	3.597720e-01	-7.548420e-04	-1.295726e-03	
50%	9.264773e-05	8.164912e-06	9.371726e-01	0.000000e+00	2.258764e-17	
75%	2.154385e-02	1.321506e-02	1.092425e+00	9.607826e-04	1.469981e-03	

```
max    8.194435e-01  8.146467e-01  4.000000e+00  3.767827e-01  4.339304e-01

                r            vx            vy            vz            wp  \
count  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06
mean   1.239124e-02 -1.253432e-04 -2.641033e-04  1.198860e-03  4.372706e-06
std    4.450773e-01  7.177616e-02  6.552093e-02  2.601583e-01  1.942947e-01
min   -3.141419e+00 -1.156056e+00 -8.621260e-01 -6.841123e+00 -1.045986e+01
25%   -3.379343e-04 -2.080171e-03 -1.373874e-03 -1.070760e-02 -5.708022e-03
50%    0.000000e+00 -1.518968e-08  1.364815e-17  3.785519e-05  0.000000e+00
75%    5.312049e-04  2.095210e-03  1.519517e-03  1.501362e-02  5.440229e-03
max    3.141577e+00  8.494385e-01  8.597021e-01  6.373837e+00  7.147506e+00

                wq            wr            ax            ay            az  \
count  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06
mean   1.434372e-04  2.558978e-03 -1.772714e-05  3.597617e-05 -2.469848e-05
std    2.135545e-01  5.107082e-01  3.168708e-01  2.945918e-01  1.454656e+00
min   -7.981405e+00 -7.181414e+00 -4.279933e+01 -3.656422e+01 -9.800000e+00
25%   -8.702793e-03 -6.507613e-05 -1.356462e-02 -7.912034e-03 -4.078746e-02
50%    0.000000e+00  0.000000e+00  0.000000e+00  0.000000e+00 -1.865757e-05
75%    8.939743e-03  3.879907e-05  1.237756e-02  8.299066e-03  3.374101e-02
max    1.179763e+01  7.300762e+00  3.906528e+01  3.332884e+01  1.921161e+02

                ap            aq            ar          RPM0          RPM1  \
count  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06
mean   1.224907e-04  5.466858e-05 -3.303912e-05  1.441162e+04  1.441290e+04
std    7.742095e+00  6.830287e+00  3.325449e+00  1.055152e+03  1.058528e+03
min   -2.510366e+03 -3.059815e+03 -2.531001e+02  9.440300e+03  9.440300e+03
25%   -4.151471e-02 -6.752393e-02 -2.696169e-04  1.438274e+04  1.438057e+04
50%    0.000000e+00  0.000000e+00  0.000000e+00  1.446835e+04  1.446836e+04
75%    4.180967e-02  6.758204e-02  3.539114e-04  1.452948e+04  1.453062e+04
max    2.711637e+03  2.831431e+03  1.630572e+02  2.166645e+04  2.166645e+04

               RPM2          RPM3            ux            uy            uz  \
count  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06  3.068233e+06
mean   1.440977e+04  1.441093e+04  6.439717e-03  3.417250e-03  8.782731e-01
std    1.058532e+03  1.058966e+03  1.058331e-01  1.010920e-01  7.641660e-01
min    9.440300e+03  9.440300e+03 -8.000000e-01 -8.000000e-01  0.000000e+00
25%    1.438241e+04  1.437958e+04  0.000000e+00  0.000000e+00  3.549988e-01
50%    1.446834e+04  1.446834e+04  0.000000e+00  0.000000e+00  9.364582e-01
75%    1.452831e+04  1.452817e+04  1.838854e-02  8.750144e-03  1.144531e+00
max    2.166645e+04  2.166645e+04  8.000000e-01  8.000000e-01  4.000000e+00

                ur
count  3.068233e+06
mean   1.285404e-02
std    4.414466e-01
min   -3.140685e+00
```

```
25%     0.000000e+00
50%     0.000000e+00
75%     0.000000e+00
max     3.141519e+00
```

[10]:
```
for i, data in enumerate(dataset):
    x, y = data
    Norm(x, df_desc)
    Norm(y, df_desc)
    dataset[i]=[x,y]
```

División del dataset para entrenamiento, validación, prueba

[11]:
```
X = []
Y = []

for sample in dataset:
    x, y = sample
    X.append(x)
    Y.append(y)

X_train, X_test, Y_train, Y_test = train_test_split(X, Y, test_size=0.05,␣
 ↪random_state=42)
X_train,  X_val, Y_train, Y_val  = train_test_split(X_train, Y_train,␣
 ↪test_size=0.1)

del X
del Y
```

[12]:
```
print(f'Total={len(dataset)}, Entrenamiento={len(X_train)}␣
 ↪({round(100*len(X_train)/len(dataset))}%),'\
      f'Validación={len(X_val)} ({round(100*len(X_val)/len(dataset))}%),'\
      f'Prueba={len(X_test)} ({round(100*len(X_test)/len(dataset))}%)')
```

```
Total=167, Entrenamiento=142 (85%),Validación=16 (10%),Prueba=9 (5%)
```

Generador de Ejemplos de entrenamiento Entrenar un modelo con una señal de 50000 datos en cada iteración sería una tarea que tomaría demasiado tiempo, así mismo, cuando se necesite realizar la inferencia del modelo, se necesitaría esa misma cantidad de datos, por lo que no se utiliza toda la señal de entrenamiento, sino pequeños segmentos de tamaño N, por lo que se generarán M-N (longitud de toda la señal, 50000) señales de longitud N para el entrenamiento, lo que aumentaría el consumo de memoria. Por tal motivo se define un generador.

[13]:
```
class DataGenerator:
    def __init__(self, X=[], Y=[], dataset = None, batch_size=512, window=512,␣
 ↪sequence_out=False, variable_window=False, delta_window=1, feedback=False,␣
 ↪window_feedback=1):
        if dataset:
```

```
            for data in dataset:
                X.append(data[0])
                Y.append(data[1])
            self.X = X
            self.Y = Y
        elif X and Y:
            if len(X)!=len(Y):
                raise Exception("La longitud de datos de X e Y deben ser␣
↪iguales")
            self.X = X
            self.Y = Y
        else:
            raise Exception("Debe especificar dataset o X, Y")

        self.n  = len(X)                  ### Número de ejemplos de entrenamiento
        x_shape = X[0].shape
        y_shape = Y[0].shape
        self.batch_size = batch_size
        self.window = window
        self.variable_window = variable_window
        self.delta_window = delta_window
        self.feedback = feedback
        self.i  = x_shape[1] if not self.feedback else x_shape[1]+y_shape[1]  ␣
↪### Número de características
        self.j  = y_shape[1]                                                  ␣
↪### Número de salidas
        #self.window_feedback = window_feedback
        if self.variable_window:
            self.window_max = self.window+self.delta_window
            self.window_min = self.window-self.delta_window
            if self.window_min<1:
                raise IndexError(f'delta_window no puede ser igual o mayor a la␣
↪ventana')
        self.sequence_out = sequence_out
        self.set_shapes()

    def set_shapes(self):
        if self.sequence_out:
            self.shapes = ((self.batch_size, self.window, self.i),
                           (self.batch_size, self.window, self.j))
        else:
            self.shapes = ((self.batch_size, self.window, self.i),
                           (self.batch_size, self.j))

    def buid_init(self):
        if self.variable_window:
            self.window = np.random.randint(self.window_min, self.window_max)
```

```
            self.set_shapes()
        self.samples = np.empty(shape= self.shapes[0], dtype='float32')
        self.labels  = np.empty(shape= self.shapes[1], dtype='float32')
        self.batchcount = 0

    def build_data(self):
        self.buid_init()
        if self.feedback:
            i_0 = 1
        else:
            i_0 = 0
        while True:
            try:
                index = np.random.randint(0, self.n-1)            ###␣
↪Trayectoria a seleccionar
                m = len(self.X[index])          ### Número de steps por ejemplo
                if m-self.window-1<=0:
                    raise IndexError(f'El tamaño de la ventana es mayor a la␣
↪trayectoria')
                else:
                    start_index = np.random.randint(i_0, int(m-self.window-1))
                    final_index = start_index+self.window
                    x = self.X[index][start_index:final_index].to_numpy()
                    if self.feedback:
                        y = self.Y[index][start_index-1:final_index-1].
↪to_numpy()
                        self.samples[self.batchcount] = np.concatenate((x,y),␣
↪axis=1)
                    else:
                        self.samples[self.batchcount] = x

                    if self.sequence_out:
                        self.labels[self.batchcount] = self.
↪Y[index][start_index:final_index].to_numpy()
                    else:
                        self.labels[self.batchcount] = self.Y[index].
↪loc[final_index]
            except IndexError as e:
                print(f'ERROR: Ejemplo {self.batchcount}: {e}')
                raise e

            self.batchcount += 1
            if self.batchcount >= self.batch_size:
                yield self.samples.astype(np.float32), self.labels.astype(np.
↪float32)
                self.buid_init()
```

[14]:
```
window = 64                     ### Número de steps por ejemplo
batch_size = 1024               ### Número de ejemplos por batch
sequence_out = False
variable_window=True
feedback = False
delta_window=window/3
```

[15]:
```
train_generator = DataGenerator(X=X_train, Y=Y_train, batch_size=batch_size,␣
 ↪window=window, sequence_out=sequence_out, variable_window=variable_window,␣
 ↪delta_window=delta_window, feedback=feedback)
val_generator   = DataGenerator(X=X_val,   Y=Y_val,   batch_size=batch_size,␣
 ↪window=window, sequence_out=sequence_out, variable_window=variable_window,␣
 ↪delta_window=delta_window, feedback=feedback)
test_generator  = DataGenerator(X=X_test,  Y=Y_test,  batch_size=batch_size,␣
 ↪window=window, sequence_out=sequence_out, variable_window=variable_window,␣
 ↪delta_window=delta_window, feedback=feedback)
```

[16]:
```
dataset_train = tf.data.Dataset.from_generator(train_generator.build_data,
                                               output_types = (tf.float32, tf.float32))
dataset_val = tf.data.Dataset.from_generator(val_generator.build_data,
                                               output_types = (tf.float32, tf.float32))
dataset_test = tf.data.Dataset.from_generator(test_generator.build_data,
                                               output_types = (tf.float32, tf.float32))
```

[17]:
```
for _ in range(5):
    x, y = next(train_generator.build_data())
    print(f'x.shape={x.shape}, y.shape={y.shape}')
```

```
x.shape=(1024, 61, 22), y.shape=(1024, 4)
x.shape=(1024, 66, 22), y.shape=(1024, 4)
x.shape=(1024, 74, 22), y.shape=(1024, 4)
x.shape=(1024, 75, 22), y.shape=(1024, 4)
x.shape=(1024, 50, 22), y.shape=(1024, 4)
```

1.4 Keras Model

1.5 Callbacks

[18]:
```
main_metric = 'mean_squared_error'
#metrics = [main_metric, 'cosine_similarity', 'logcosh']
metrics = main_metric
```

Early Stopping

[19]:
```
Early_Stopping = tf.keras.callbacks.EarlyStopping(monitor=f'val_{main_metric}',␣
 ↪min_delta=0, patience=15, verbose=0, mode='auto')
```

Plotting

[20]:
```
class PlotLosses(tf.keras.callbacks.Callback):
    def __init__(self, loss, figsize=(10,10)):
        self.loss = loss
        self.figsize = figsize

    def on_train_begin(self, logs={}):
        self.i = 0
        self.x = []
        self.losses = []
        self.val_losses = []
        self.logs = []
        self.fig = plt.figure(figsize=self.figsize)
        if type(self.loss)==list:
            self.N = len(self.loss)
            for i in range(self.N):
                self.losses.append([])
                self.val_losses.append([])
        else:
            self.N = 1

    def on_epoch_end(self, epoch, logs={}):
        self.logs.append(logs)
        self.x.append(self.i+1)
        if self.N>1:
            for i, l in enumerate(self.loss):
                self.losses[i].append(logs.get(f'{l}'))
                self.val_losses[i].append(logs.get(f'val_{l}'))
        else:
            self.losses.append(logs.get(f'{self.loss}'))
            self.val_losses.append(logs.get(f'val_{self.loss}'))
        self.i += 1

        clear_output(wait=True)
        if self.N>1:
            self.fig, self.axs = plt.subplots(self.N, sharex=True, figsize=self.
↪figsize)
            for i, l in enumerate(self.loss):
                self.axs[i].plot(self.x, self.losses[i], label=f"Train")
                self.axs[i].plot(self.x, self.val_losses[i],␣
↪label=f"Validation")
                self.axs[i].set_title(f'{l}')
                self.axs[i].set_yscale('log')
                self.axs[i].grid()
                self.axs[i].legend()
            self.axs[i].set_xlabel('Epochs')
        else:
            plt.plot(self.x, self.losses, label=f"Train")
```

```
            plt.plot(self.x, self.val_losses, label=f"Validation")
            plt.suptitle(f'{self.loss}')
            plt.yscale('log')
            plt.xlabel('Epochs')
            plt.grid()
            plt.legend()
        plt.show()
```

Checkpoints

[21]:
```
checkpoint_filepath = './tmp/checkpoint'
model_checkpoint_callback = tf.keras.callbacks.ModelCheckpoint(
    filepath=checkpoint_filepath,
    save_weights_only=True,
    monitor=f'val_{main_metric}',
    mode='min',
    save_best_only=True)
```

[22]:
```
plot_losses = PlotLosses(loss=metrics)
#callbacks = [model_checkpoint_callback, Early_Stopping, plot_losses]
callbacks = [model_checkpoint_callback, plot_losses]
```

Definición del Modelo

[23]:
```
input_dim = len(states_list) if not feedback else len(states_list)+len(rpm_list)
output_dim = len(rpm_list)
print(f'input_dim: {input_dim}, output_dim: {output_dim}')
```

```
input_dim: 22, output_dim: 4
```

[24]:
```
model = models.Sequential()
model.add(layers.LSTM(256, input_shape=(None, input_dim),␣
 ↪return_sequences=True))
#model.add(layers.Conv1D(filters=256, kernel_size=7, padding='same',␣
 ↪activation='relu'))
model.add(layers.LSTM(128, return_sequences=True))
#model.add(layers.Conv1D(filters=128, kernel_size=7, padding='same',␣
 ↪activation='relu'))
model.add(layers.LSTM(64, return_sequences=True))
#model.add(layers.Conv1D(filters=64, kernel_size=7, padding='same',␣
 ↪activation='relu'))
model.add(layers.LSTM(32))
#model.add(layers.LSTM(shapes[1][1]))#, return_sequences=True))
model.add(layers.Dense(512, activation='relu'))
model.add(layers.Dense(256, activation='relu'))
model.add(layers.Dense(128, activation='relu'))
model.add(layers.Dense(64, activation='relu'))
model.add(layers.Dense(output_dim))
```

Optimizador con learning decay

[25]:
```
# lr_schedule = tf.keras.optimizers.schedules.ExponentialDecay(
#     initial_learning_rate=5e-3,
#     decay_steps=len(X_train),
#     decay_rate=0.95)
# optimizer = tf.keras.optimizers.Adam(learning_rate=lr_schedule)
#optimizer = tf.keras.optimizers.Adam(learning_rate=5e-4)
optimizer = tf.keras.optimizers.Adam(learning_rate=0.0001, clipvalue=0.5)
#optimizer = tf.keras.optimizers.Adam()
```

Compilado el Modelo

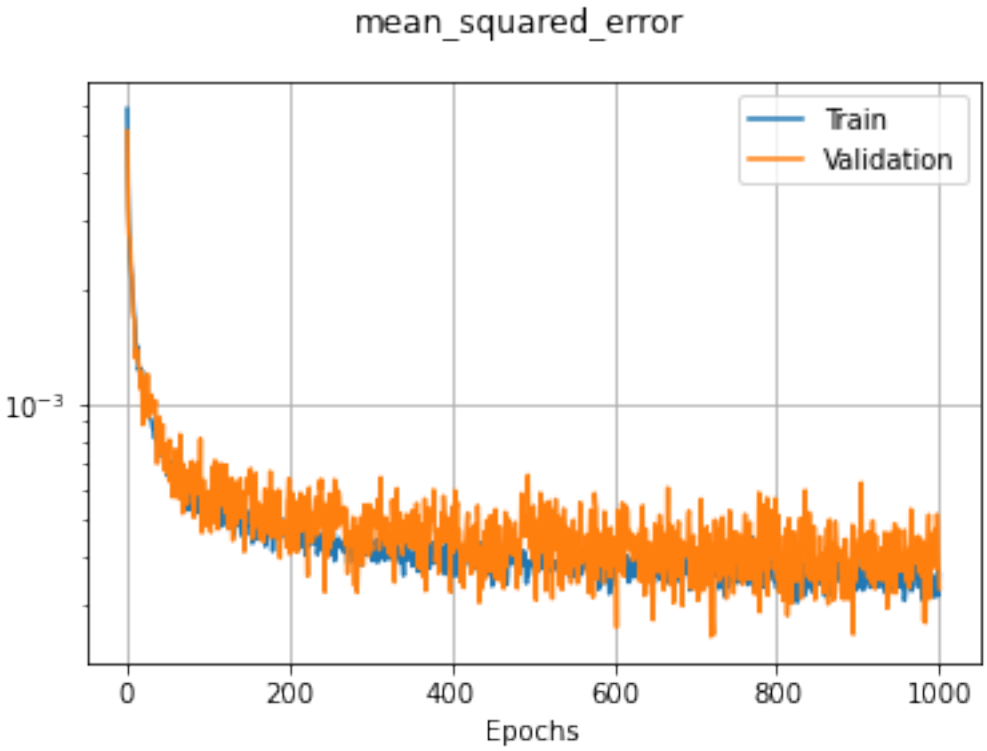
[26]:
```
model.compile(loss=main_metric, optimizer=optimizer, metrics=metrics)
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm (LSTM)                  (None, None, 256)         285696
_________________________________________________________________
lstm_1 (LSTM)                (None, None, 128)         197120
_________________________________________________________________
lstm_2 (LSTM)                (None, None, 64)          49408
_________________________________________________________________
lstm_3 (LSTM)                (None, 32)                12416
_________________________________________________________________
dense (Dense)                (None, 512)               16896
_________________________________________________________________
dense_1 (Dense)              (None, 256)               131328
_________________________________________________________________
dense_2 (Dense)              (None, 128)               32896
_________________________________________________________________
dense_3 (Dense)              (None, 64)                8256
_________________________________________________________________
dense_4 (Dense)              (None, 4)                 260
=================================================================
Total params: 734,276
Trainable params: 734,276
Non-trainable params: 0
_________________________________________________________________
```

Entrenamiento del Modelo

[27]:
```
%%time
EPOCHS = 1000
#se usa el repeat para llamar al generador mas de una vez
#steps_per_epoch  = numero de batches de los datos para determinar una epoca␣
 ↪terminada
```

```
#Por defecto -> number of samples in your dataset divided by the batch size␣
 ↪(LEN_DT//BATCH_SIZE_TRAIN)
#verbose = mostrar el avance del entrenamiento
#validation_steps = numero de batches de datos para validar en cada epoca
#workers?
#max_queue_size?
history = model.fit(dataset_train.repeat(),
                    epochs=EPOCHS,
                    steps_per_epoch = len(X_train),
                    callbacks=callbacks,
                    verbose=1,
                    validation_data = dataset_val.repeat(),
                    validation_steps= len(X_val))
```




```
Wall time: 17h 35min 32s
```

Se guarda el Modelo

[28]:
```
I = 8
```

[29]:
```
model.save(f'../Models/{dataset_name}_{I}.h5')
print(f'../Models/{dataset_name}_{I}.h5')
```

```
../Models/Dataset_Final_8.h5
```

1.5.1 Evaluación del Modelo

Se carga el modelo

[30]:
```
model = tf.keras.models.load_model(f'../Models/{dataset_name}_{I}.h5')
model.summary()
```

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
lstm (LSTM)                  (None, None, 256)         285696
_________________________________________________________________
lstm_1 (LSTM)                (None, None, 128)         197120
_________________________________________________________________
lstm_2 (LSTM)                (None, None, 64)          49408
_________________________________________________________________
lstm_3 (LSTM)                (None, 32)                12416
_________________________________________________________________
dense (Dense)                (None, 512)               16896
_________________________________________________________________
dense_1 (Dense)              (None, 256)               131328
_________________________________________________________________
dense_2 (Dense)              (None, 128)               32896
_________________________________________________________________
dense_3 (Dense)              (None, 64)                8256
_________________________________________________________________
dense_4 (Dense)              (None, 4)                 260
=================================================================
Total params: 734,276
Trainable params: 734,276
Non-trainable params: 0
_________________________________________________________________
```

Evaluación con dataset de prueba

[31]:
```
%%time
N = 0
for i in range(len(X_test)):
    N+=len(X_test[i])
N=N/len(X_test)

n_batches = np.ceil(N/batch_size)
losses = model.evaluate(dataset_test, steps = n_batches)
K = df_desc[rpm_list[0]][7]-df_desc[rpm_list[0]][3] #Ganancia del actuador
print(f'K={"{:.2f}".format(K)}')
if not type(metrics) == list:
    metrics = [metrics]
for i, l in enumerate(['loss']+metrics):
```

```
    print(f'{l}: {"{:.2e}".format(losses[i])} -> {"{:.2f}".format(losses[i]*K)}␣
↪RPM')
```

```
23/23 [==============================] - 8s 270ms/step - loss: 5.1904e-04 -
mean_squared_error: 5.1904e-04
K=12226.15
loss: 5.19e-04 -> 6.35 RPM
mean_squared_error: 5.19e-04 -> 6.35 RPM
Wall time: 8.09 s
```

Evaluación con 1 trayectoria

[32]:
```
window_test = 3000
test_traj_generator  = DataGenerator(X=X_test,  Y=Y_test,  batch_size=1,␣
↪window=window_test, sequence_out=True, feedback=feedback)
```

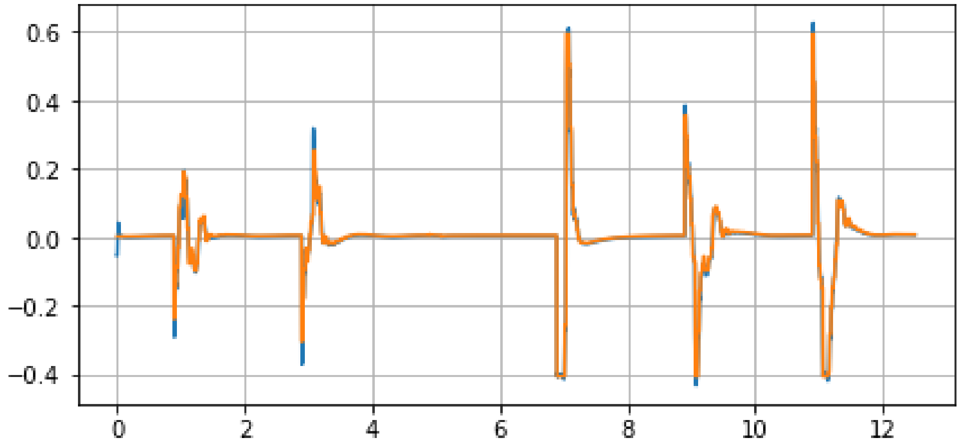
[33]:
```
%%time
X, Y = next(test_traj_generator.build_data())
x = X[0]
y = Y[0]
y_pred = []
for i in range(0, len(x)):
    if i == 0:
        x_temp = x[0].reshape(1,  1, X.shape[2])
    elif i<=window:
        x_temp = x[0:i].reshape(1,  i, X.shape[2])
    else:
        x_temp = x[i-window:i].reshape(1,  window, X.shape[2])
    y_temp = model.predict(x_temp)
    y_pred.append(y_temp)
y_pred = np.array(y_pred).reshape(y.shape)
```

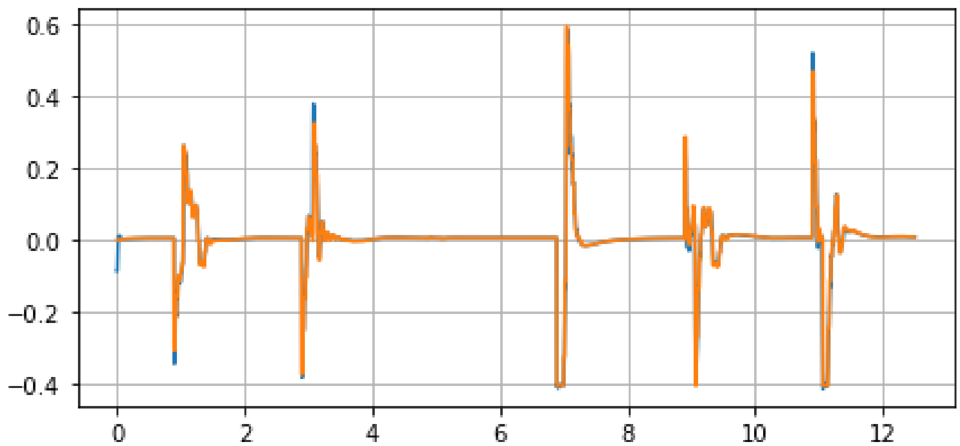
```
Wall time: 1min 58s
```

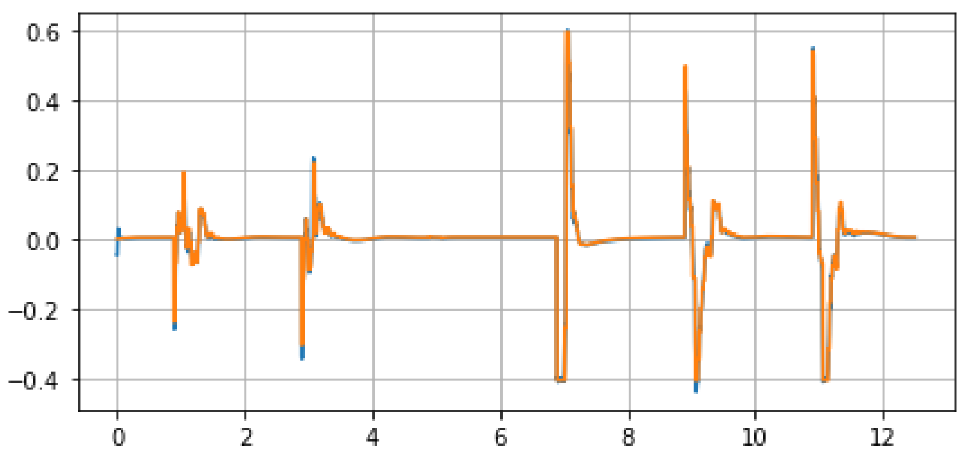
Visualización con 1 trayectoria

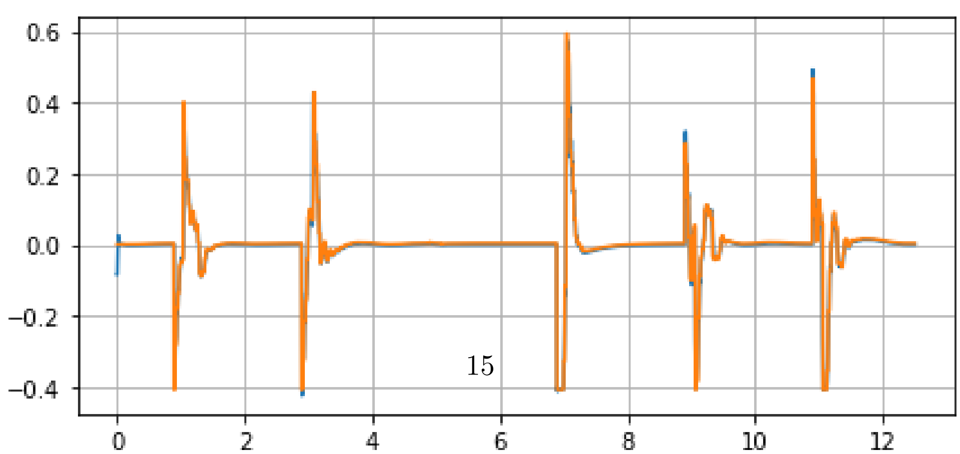
[34]:
```
t = np.arange(0, len(y)*Ts, Ts)
```

[35]:
```
fig, axs = plt.subplots(Y.shape[2], figsize = (7,15))
for i in range(Y.shape[2]):
    axs[i].plot(t, y_pred[:,i], t, y[:,i])
    axs[i].grid()
```

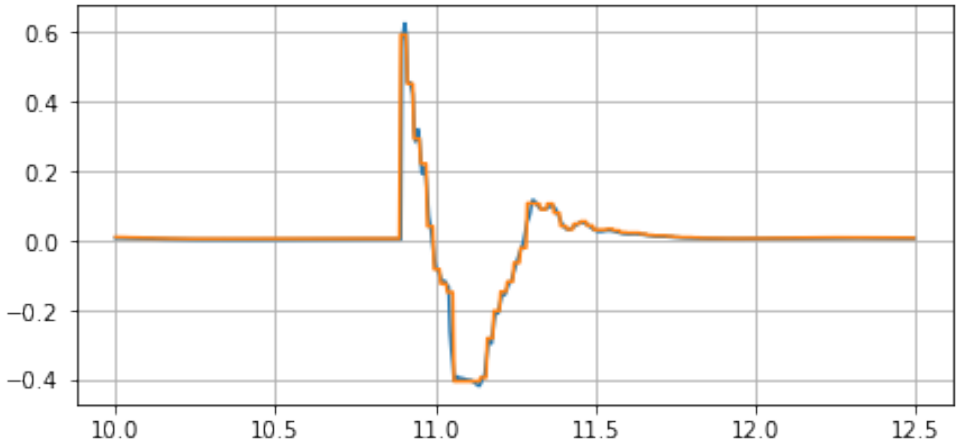

0.6
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12

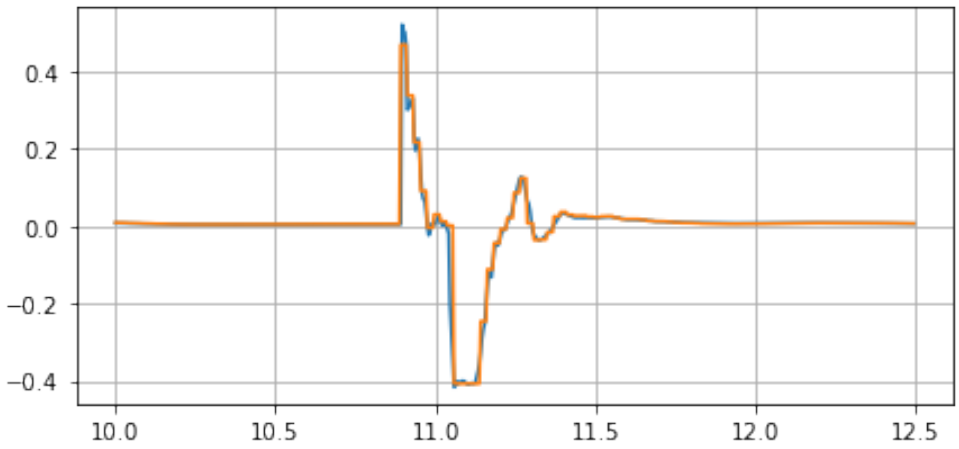

0.6
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12

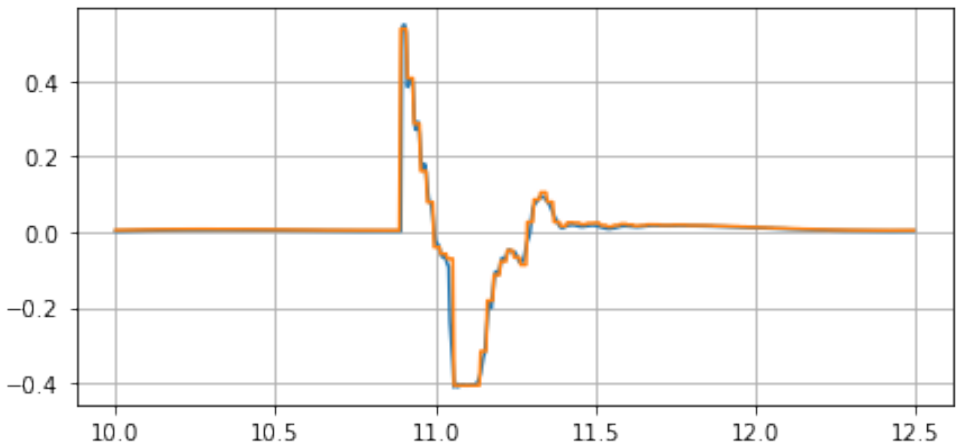

0.6
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12

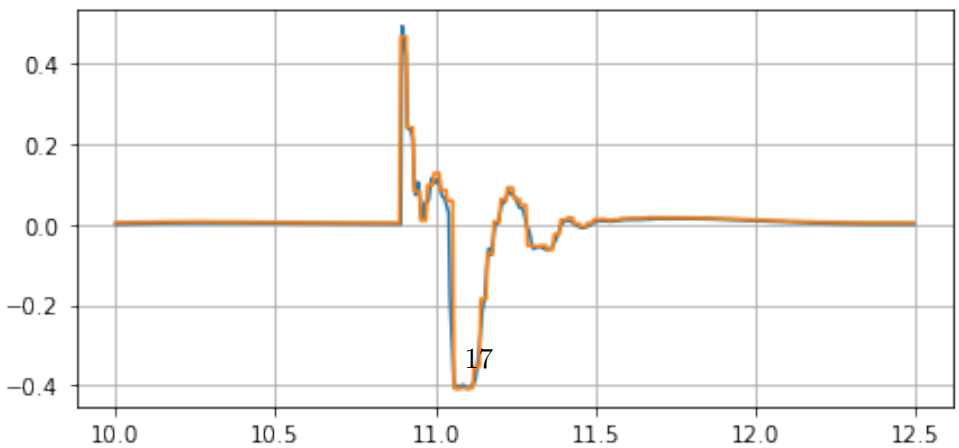

0.6
0.4
0.2
0.0
−0.2
−0.4
0
2
4
6
8
10
12

[36]:
```
fig, axs = plt.subplots(Y.shape[2], figsize = (7,15))
L1 = 4*len(t)//5
L2 = 5*len(t)//5
for i in range(Y.shape[2]):
    axs[i].plot(t[L1:L2], y_pred[L1:L2,i], t[L1:L2:], y[L1:L2:,i])
    axs[i].grid()
```


0.6
0.4
0.2
0.0
−0.2
−0.4
10.0
10.5
11.0
11.5
12.0
12.5


0.4
0.2
0.0
−0.2
−0.4
10.0
10.5
11.0
11.5
12.0
12.5


0.4
0.2
0.0
−0.2
−0.4
10.0
10.5
11.0
11.5
12.0
12.5


0.4
0.2
0.0
−0.2
−0.4
10.0
10.5
11.0
11.5
12.0
12.5

Tiempo de inferencia tamaño entrada

[37]:
```
import time

def MSE(y, y_pred):
    return (y-y_pred)**2

window_test = 1000
test_traj_batch = 100
test_traj_generator  = DataGenerator(X=X_test,  Y=Y_test, ␣
 ↪batch_size=test_traj_batch, window=window_test, sequence_out=True)

window_len = []
inf_time = []
loss = []

x, y = next(test_traj_generator.build_data())
```

[38]:
```
%%time
accum_time = 0
n_iter = 100
test_range = list(set(np.rint(np.logspace(0, np.log10(x.shape[1]-1),␣
 ↪num=n_iter, endpoint=True))))
test_range.sort()
n_iter = len(test_range)
for k, i in enumerate(list(map(int,test_range))):
    inf_time_aux = []    # Tiempo de inferencia auxiliar
    loss_aux = []    # Costo Auxiliar
    init_time = time.time()
    for j in range(len(x)):
        x_5 = x[j][0:i].reshape(1,  i, x.shape[2])
        start_time = time.time()
        y_pred = model.predict(x_5)
        finish_time = time.time() - start_time
        inf_time_aux.append(finish_time)
        loss_aux.append(
            np.mean(
                MSE(y[j][i], y_pred)
            )
        )

    window_len.append(i)
    inf_time.append(np.mean(inf_time_aux))
    loss.append(np.mean(loss_aux))
    clear_output(wait=True)
```

```
    accum_time += time.time()-init_time
    print(f'iter = {k} de {len(test_range)}, i = {i}, execution time = {"{:.
↪2f}".format(np.max(accum_time))}s')
```

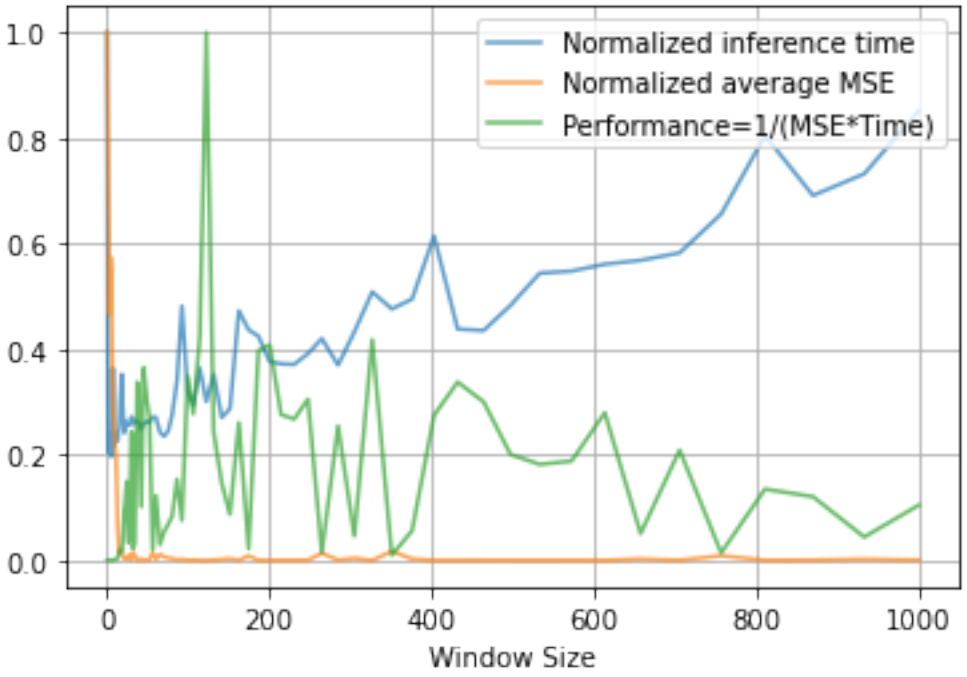
```
iter = 74 de 75, i = 999, execution time = 475.33s
Wall time: 7min 55s
```

[39]:
```
inf_time_norm = np.array(inf_time)/max(inf_time)
loss_norm = np.array(loss)/max(loss)
performance = 1/(np.array(loss)*np.array(inf_time))
performance = np.array(performance)/max(performance)
```

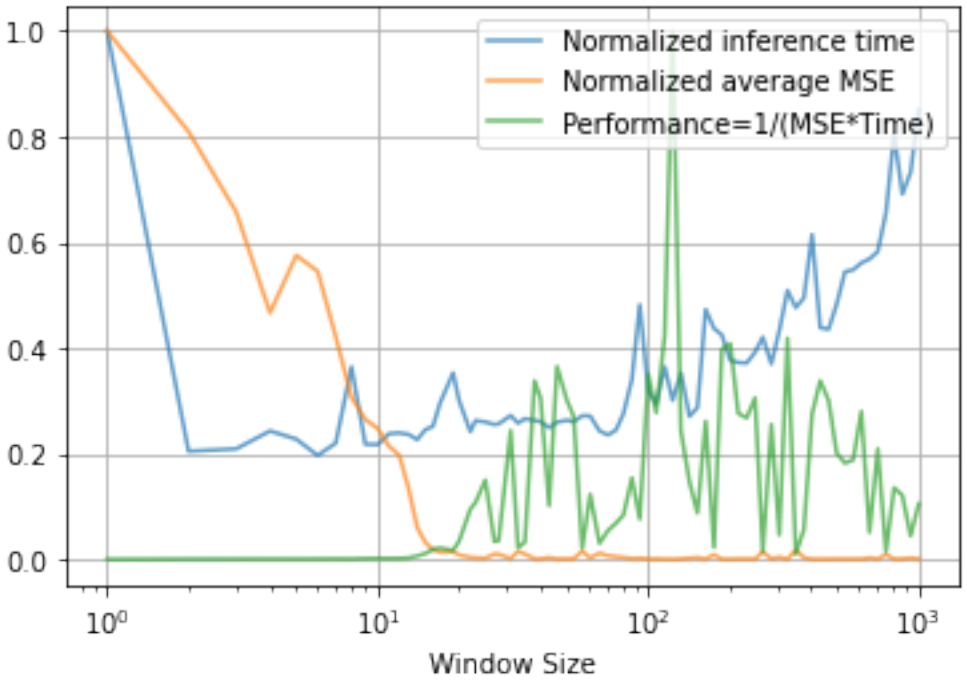
[40]:
```
plt.figure()
plt.plot(window_len, inf_time_norm, label='Normalized inference time', alpha=0.
↪7)
plt.plot(window_len, loss_norm, label='Normalized average MSE', alpha=0.7)
plt.plot(window_len, performance, label='Performance=1/(MSE*Time)', alpha=0.7)
plt.xlabel("Window Size")
plt.legend(loc=1)
plt.grid()

print(f'Best window inference time={np.argmin(inf_time_norm)} steps, time={"{:.
↪2f}".format(np.min(inf_time)*1000)} ms')
print(f'Best window MSE loss={np.argmin(loss_norm)} steps, MSE={"{:.2e}".
↪format(np.min(loss))}')
print(f'Best window Performance (MSExTime)={np.argmax(performance)} steps,␣
↪Value={"{:.2e}".format(np.max(loss)/np.min(inf_time))}')
```

```
Best window inference time=5 steps, time=33.66 ms
Best window MSE loss=44 steps, MSE=5.98e-05
Best window Performance (MSExTime)=44 steps, Value=6.13e+00
```



[41]:
```
plt.figure()
plt.semilogx(window_len, inf_time_norm, label='Normalized inference time',␣
 ↪alpha=0.7)
plt.semilogx(window_len, loss_norm, label='Normalized average MSE', alpha=0.7)
plt.semilogx(window_len, performance, label='Performance=1/(MSE*Time)', alpha=0.
 ↪7)
plt.xlabel("Window Size")
plt.legend(loc=1)
plt.grid()
```


Normalized inference time
Normalized average MSE
Performance=1/(MSE*Time)
1.0
0.8
0.6
0.4
0.2
0.0
10^0
10^1
10^2
10^3
Window Size

[ ]: