TUD Seminar – Neural Networks, Deep Learning and Applications

FSD Fahrzeugsystemdaten GmbH

FSD Fahrzeugsystemdaten GmbH is the central authority according to the German Road Traffic Act (StVG) for the further development of the main inspection (HU), the innovative testing technologies required for it, including vehicle-specific requirements, and for the creation of decision-making bases for the homologation (approval) of new vehicles.

The braking system plays a crucial role in the safety of a vehicle. As part of the main inspection according to §29 StVZO, the inspection of the braking system is therefore firmly established. The corresponding procedures and conditions of the HU Brakes Directive must be applied to identify any defects and faults, ensuring vehicle and traffic safety.

For this, FSD GmbH has developed a procedure that uses a three-axis acceleration and rotation rate sensor to record longitudinal, lateral, and vertical acceleration (ax, ay, and az) and roll, pitch, and yaw rates (dx, dy, and dz) at a sampling rate of 100 Hz, in order to analyze the braking behavior of the vehicle in a dynamic test drive.

Based on the recorded measurement sequences of accelerations and angular velocities, a neural network is trained. This network is then generalized and is intended to predict, for measurement series of brake tests of unknown vehicles, whether the vehicle's brakes are intact or have defects.

Classifying Deceleration Measurement sequences

Topic 2 – Bias in the Dataset

Two datasets are provided: Train.pkl and Test.pkl. Both contain measurement series from deceleration measurements, consisting of linear accelerations and angular velocities in the x-, y-, and z-directions, recorded by the HU adapter sensors. Additionally, metadata is included, such as the condition of the brakes, information about the manufacturer and model of the vehicle, and the average deceleration during the measurement. During the entire project, use Train.pkl for training the models and Test.pkl for testing the models.

Task 1: FCN, 2D CNNs vs. LSTMs Parameter Tests & Comparison

In this task, a Fully Convolutional Network (FCN), a 2D Convolutional Neural Network (CNN), and a Long Short-Term Memory (LSTM) network will be tested and compared. These networks will be trained with the deceleration measurement series to classify the vehicle's braking system as either defective or not defective. The dataset contains measurements from both functional and manipulated brakes, with different brakes being manipulated and various combinations of manipulated brakes. You will find this information in the dataset.

A1.1:

- *Implement an FCN, a 2D CNN, and an LSTM that take the recorded measurement series with the three linear accelerations and angular velocities of the deceleration measurements as input.*

A1.2:

- *Use the Random-Split Validation method for training and validating the networks. For the training and evaluation of the networks through Random Split Validation, use only the Train.pkl dataset. Then test your models with the Test.pkl dataset to detect potential overfitting on the training data.*

- *Identify the adjustable hyperparameters of the models and test various combinations.*

- *Evaluate the results using accuracy (Accuracy) and present them.*

- *For each model, select a parameter setting, compare the results, and consider the training times. Provide a recommendation for the model with a brief explanation.*

Task 2: Generative AI

The inspection of the braking system is an important tool for experts during the main inspection. To improve this technology, the training dataset should be expanded. This task focuses on the application of Generative Adversarial Networks (GANs) and Recurrent Neural Networks (RNNs) to generate measurement series that will be integrated into the existing dataset.

A2.1:

- *Implement a Generative Adversarial Network (GAN) to generate synthetic measurement series from the existing deceleration measurements. Train the GAN with Train.pkl and evaluate the realism of the generated measurement series and how well they reflect the real distribution.*

- *Implement a Recurrent Neural Network (RNN) for generating synthetic measurement series (similar to the 1st Coding Lab) and train it also with Train.pkl. Evaluate the realism of the generated measurement series and how well they reflect the real distribution.*

- *Compare the quality of the measurement series from both models and discuss their advantages and disadvantages.*

A2.2:

- *Add the synthetic measurement series from the GAN and RNN to Train.pkl and expand the training dataset. Train the best model from Task 1.2 (FCN, CNN, or LSTM) with the expanded dataset and test it with Test.pkl. Analyze whether the expansion leads to an improvement in model accuracy.*

Additional Task 1: Explainable AI

The inspection of the braking system is an important tool for experts during the main inspection. To gain trust in a technology, it is necessary to understand how it works. In connection with this task, the concept of "Explainable AI" (XAI) is at the forefront, which has gained importance in both research and industry in recent years. The main goal of XAI is to make otherwise opaque machine learning models more understandable, transparent, and interpretable by explaining the so-called "black box" algorithms.

A1:

- *Familiarize yourself with the XAI Python packages SHAP [3] and LIME [4].*

- *Choose one XAI method from each package that is suitable for making the workings of the neural network from Task 1 transparent and explaining its predictions, and apply the selected methods to the best network from Task 1.*

- *The goal here is to find out which features/samples were crucial for the network's prediction and to better understand the prediction. Consider an appropriate representation for this. You can get inspiration from [5].*
- *Which of the two methods would you recommend to make the inspection of the braking system based on neural networks more transparent in the future and make the classifier's decision understandable?*

Additional Task 2: Ensemble Classifiers

Ensemble methods combine the predictions of multiple models to improve overall performance. In this task, various neural networks are to be combined to reach a final classification through voting (e.g., Voting or Averaging). Networks like CNNs, LSTMs, FCNs, and CNNs with attention layers can be used. Additionally, it is possible to develop networks that separately consider individual signal channels and combine their results. Your creativity should have no limits in this task.

A2:

- Use different ensemble methods to combine multiple networks and merge their predictions into a final result (e.g., Voting, Averaging, Stacking).
- Create an ensemble of different networks. You can also implement networks that analyze only one signal channel of the measurement data and combine their results, or networks that you have invented yourself, or networks that you have seen in other projects.
- Test the ensemble on the provided datasets and compare its performance with the individual models from Task 1.
- Discuss the advantages and disadvantages of the methods used.

Literaturhinweise:

[1] CNN:

http://yann.lecun.com/exdb/publis/pdf/lecun-99.pdf

https://towardsdatascience.com/a-comprehensive-guide-to-convolutional-neural-networks-the-eli5-way-3bd2b1164a53

https://cs231n.github.io/convolutional-networks/

[2] LSTM:

http://colah.github.io/posts/2015-08-Understanding-LSTMs/

[3] Shap:

https://github.com/slundberg/shap

[4] Lime:

https://arxiv.org/pdf/1602.04938.pdf

https://github.com/marcotcr/lime

[5]

https://github.com/marcotcr/lime/blob/master/doc/notebooks/Tutorial%20-%20Image%20Classification%20Keras.ipynb

[6] GAN:

https://arxiv.org/pdf/1406.2661.pdf

https://machinelearningmastery.com/what-are-generative-adversarial-networks-gans/

[7] VAE:

https://arxiv.org/abs/1312.6114