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: Bias in the Dataset

In deep learning, the quality of the data plays a crucial role in the success of a model. Often, datasets need to be expanded, cleaned, or adjusted to maximize the model's performance. This may be necessary because the existing data is incomplete or contains errors, or because it is difficult to collect sufficient data. Additionally, data often needs to be transformed into a suitable format that the model can process. In many cases, it is also necessary to synthesize existing data to enable more accurate modeling and to increase the diversity of the data. To address these challenges, this task focuses on the application of generative models, such as GANs and RNNs, to generate synthetic data and expand the dataset, which should lead to a potential improvement in model accuracy.

A2.1:

- *Use the best network from Task 1 for this task. Accuracy describes how many of the total data points were classified correctly, but it is often useful to take a closer look at the cases where a network has difficulties generalizing. Analyze your network's performance in relation to the metadata that is known about the dataset. Investigate how different metadata (e.g., vehicle model, deceleration, speed, ...) affects the model's performance. Identify in which deceleration measurements the model performs well and where its performance is suboptimal.*
- *Research the methods available for data preprocessing and examine how different preprocessing techniques (e.g., standardization, min-max scaling) impact the model's accuracy.*
- *In deep learning, data augmentation is a method that is often applied. Research this technique and perform data augmentation with the data from Train.pkl (e.g., oversampling rare classes). Investigate the impact of the data augmentation used on model accuracy. Test your models trained with data augmentation using Test.pkl.*

A2.2:

- *In the next step, implement a debiasing variational autoencoder (similar to Coding Lab 2), train it with Train.pkl, and evaluate it with Test.pkl.*
- *Compare the results of the debiasing autoencoder with the results of the best network from Task 1. Make a statement about the generalizability of the networks in brake testing. Which method provides a more reliable and general classification? What other ideas do you have to minimize bias in the classification?*

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.

Z1:

- *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.

Z2:

- 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:

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

[3] Shap:

https://github.com/slundberg/shap

[4] Lime:

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https://github.com/marcotcr/lime

[5]

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

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