Development of automatic illegal replacement muffler detection system at NTSEL

National Traffic Safety and Environment Laboratory

Aim

NTSEL is working on developing automatic sensing system from remote location, which detects vehicles equipped with illegal replacement muffler traveling on the road.
This presentation shows elemental technologies that have been developed for this purpose and the current status of research.

Outline

- Real-time noise source localization technique
- Judgment method of illegal replacement muffler from pass-by noise
- Research in progress

Real-time noise source localization technique

- When road traffic noise is measured with a single microphone, it is not possible to measure individual vehicle's noise in the traffic flow.
- Therefore, NTSEL developed a system that can measure each vehicle’s pass-by noise in the traffic flow separately by using a microphone array.
- Microphone array is consisted of 31 microphones and a camera.
- Sound source localization is calculated by delay and sum beamforming algorithm.
- The calculation is executed by FPGA (Field Programmable Gate Array) and results are obtained at 25fps.
- The system can measure sound pressure level emitted by a vehicle, but it cannot judge whether it is a vehicle equipped with illegal replacement exhaust muffler or not because it is judged by result of proximity stationary test in Japan.

Judgment method of illegal replacement exhaust muffler from pass-by noise

Background

In Japan, street inspection is conducted by proximity stationary noise test.
In case the results of the measurements exceed the limit value, a maintenance order will be issued.
In this study, a replacement muffler which proximity stationary noise level exceeds its limit value is defined as "illegal replacement muffler".

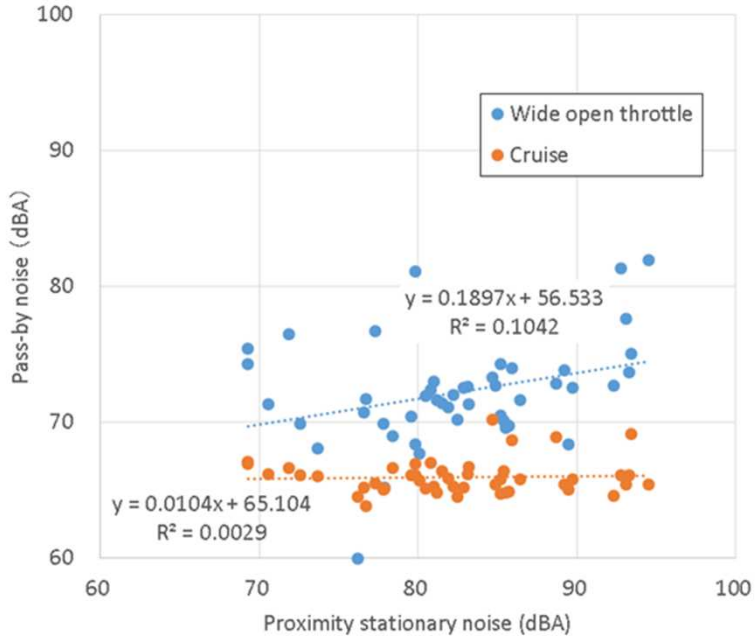
Street inspection

Real driving

Proximity stationary noise test : Vehicle is standstill Engine speed is determined by the test method	Vehicle Status ⟷	Speed, acceleration, engine speed, etc. are unknown
50cm from muffler's rear edge	Microphone position ⟷	A few meters from the vehicle Depending on location

Background

- There is no correlation between proximity stationary noise and pass-by noise because the contribution rate of the noise source (engine, intake/exhaust, tires, etc.) at the measurement point is different each other.
- Therefore, it is difficult to illegal replacement muffler from pass-by noise.



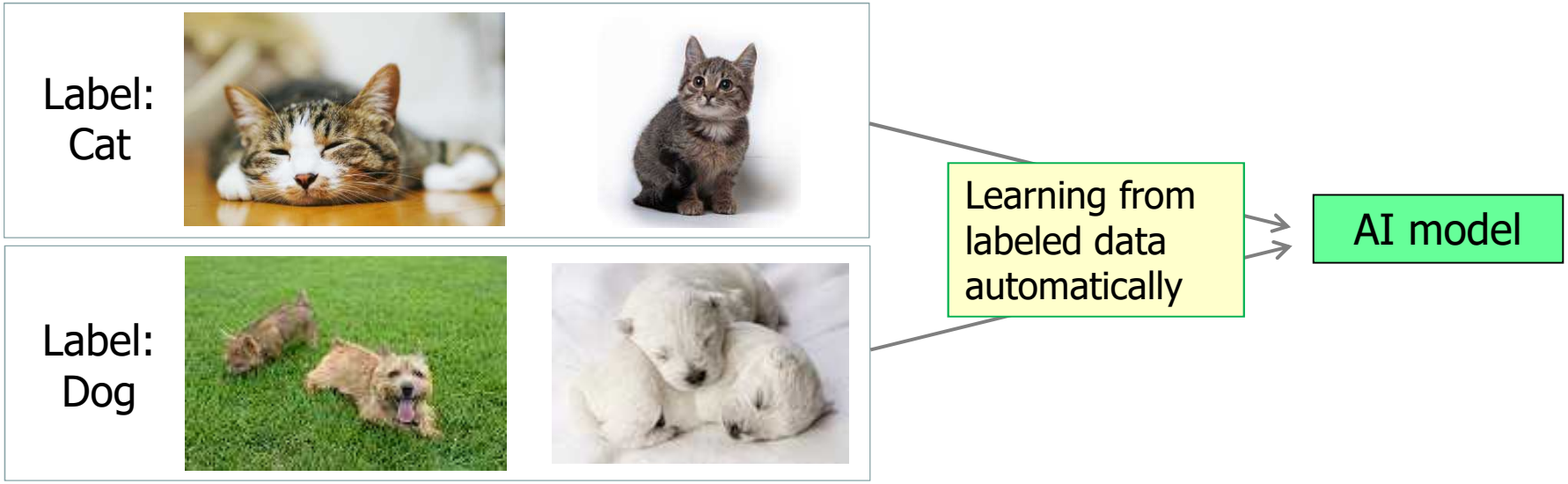
Aim

- Based on these backgrounds, use of AI was considered in this study. If it is possible to judge illegal replacement muffler from pass-by noise, it will be possible to conduct more efficient enforcement.

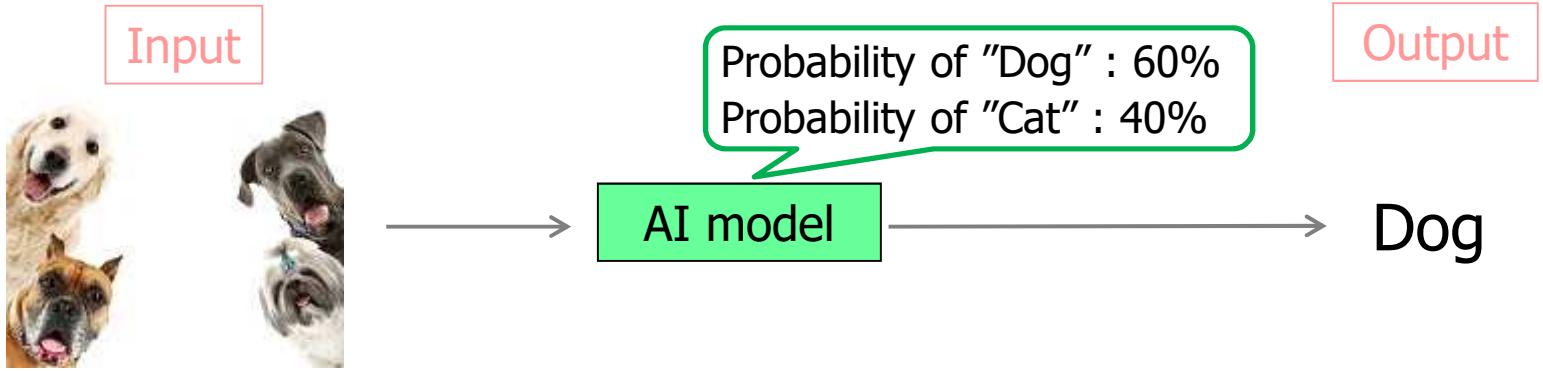
Deep learning : Classification of supervised learning

Deep learning is a program which automatically learns the process of obtaining an output from labeled data for a given input data and finds an answer.

Creating AI model



Judgement by AI model



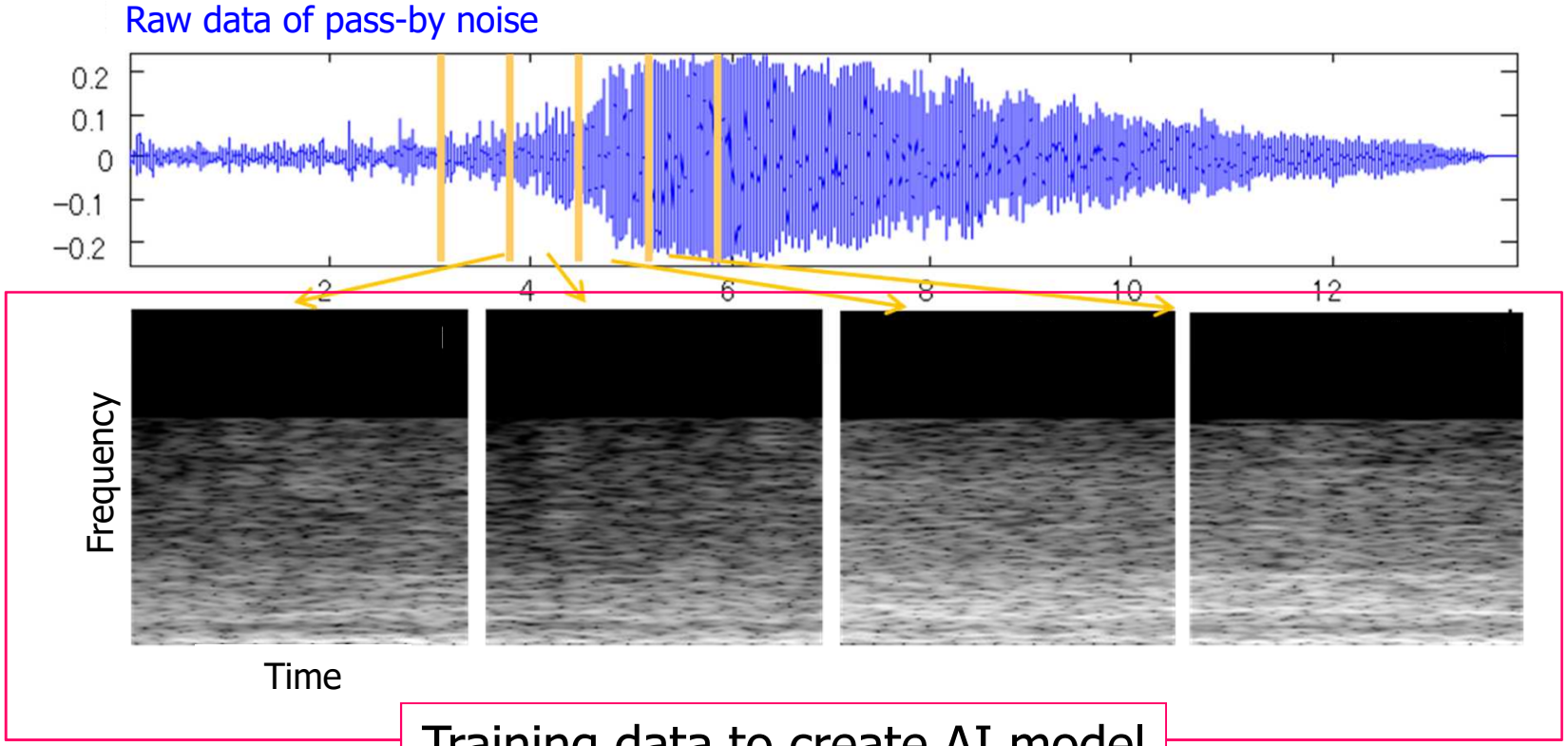
Measurement of training data

- Deep learning applied in this study is supervised learning classification.
- Supervised learning classification requires training data, so training data is measured at test site.
- We will create AI model to classify illegal replacement muffler and legal mufflers. So, we measured 3 legal vehicles (normal muffler) and 3 illegal vehicles (illegal replacement muffler). Measurement are conducted by driving the vehicle at various speeds and accelerations.
- The illegal replacement mufflers are not allowed to be used on public roads. We confirmed that proximity stationary noise level exceeded its limit value.
- In this study, the vehicle was assumed to be a motorcycle running alone. The pass-by noise was measured with a single microphone.

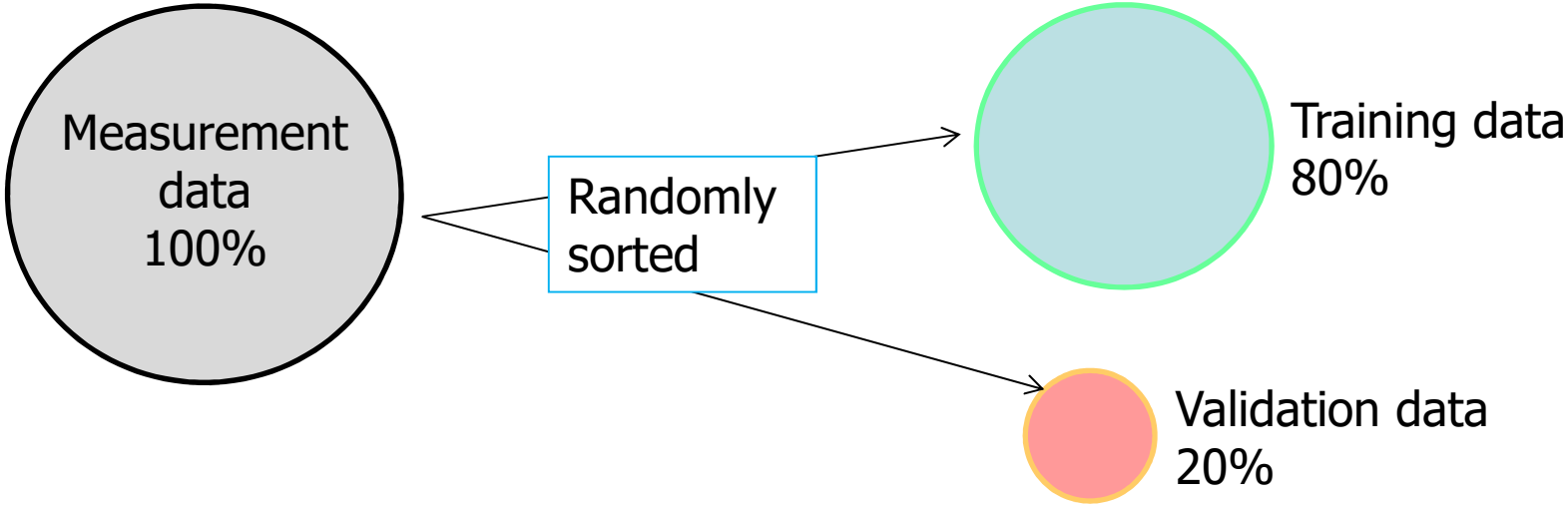
Measurement of training data at test site

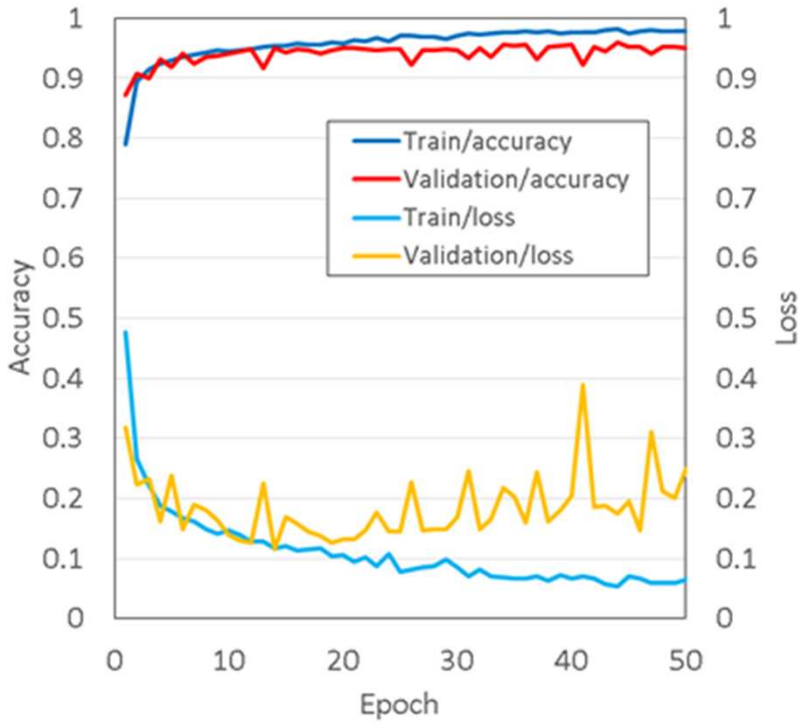
Pre-processing

- Measured pass-by noise is converted into time-frequency images and using them as training data.
- These images are normalized by the maximum value of each image.
- Since measurement distance varies on public roads, it is more effective to focus on the frequency pattern rather than SPL.
- In creating the AI model, the areas with large changes in the images are recognized as features, so normalization is considered appropriate in the sense of emphasize the features in each image.



Creating AI model

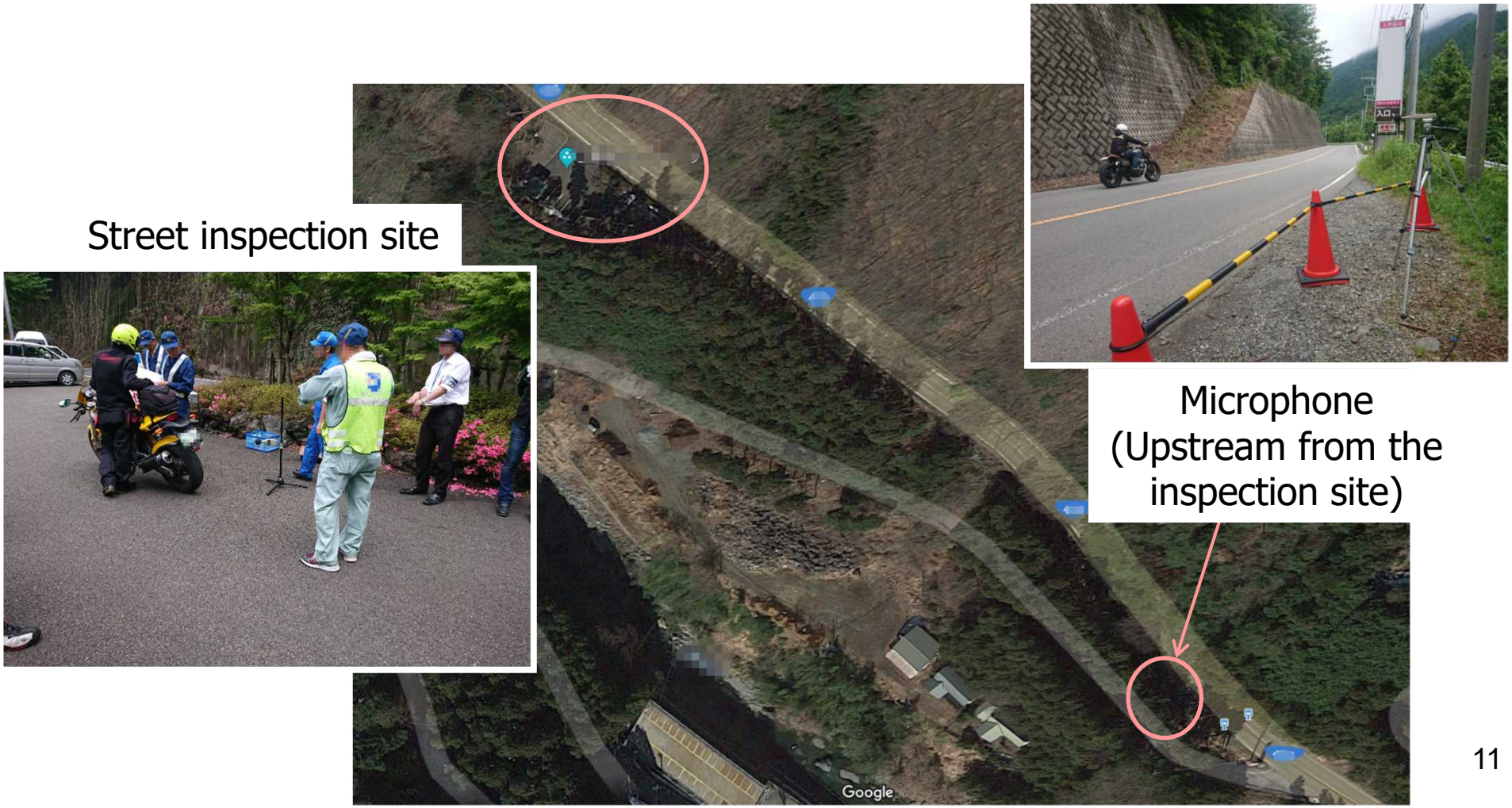




- "Accuracy" is the percentage of correct answers.
- "Loss" is sum of squared error. (Lower value means good model.)
- Accuracy is 90% or higher for both training and validation.
- Validation/loss increases around generation 30, and there is a possibility of overlearning. -> 25th model is used in this study.
- It is necessary to consider the generality of AI model for vehicles that are uncorrelated with the vehicle used to create the training data.

Measurement at public road

To measure vehicle's pass-by noise that are uncorrelated with the vehicles used to create the training data, measurement at public road was conducted.
Recorders stood at the locations where microphone was installed site and street inspection site, and checked vehicle appearance and its proximity stationary noise level.



Results for uncorrelated vehicles

- All measured pass-by noise were converted into time-frequency images to apply created AI model.
- 6 vehicles were measured at public road. All of them were uncorrelated with the vehicles which were used to create the training data. AI model can judge 5 vehicles correctly.
- According to proximity stationary noise level, some vehicles were difficult to be judged by human, and AI model made highly accurate judgments without inputting any other information (e.g. vehicle speed, acceleration, engine speed, measurement distance, etc.).

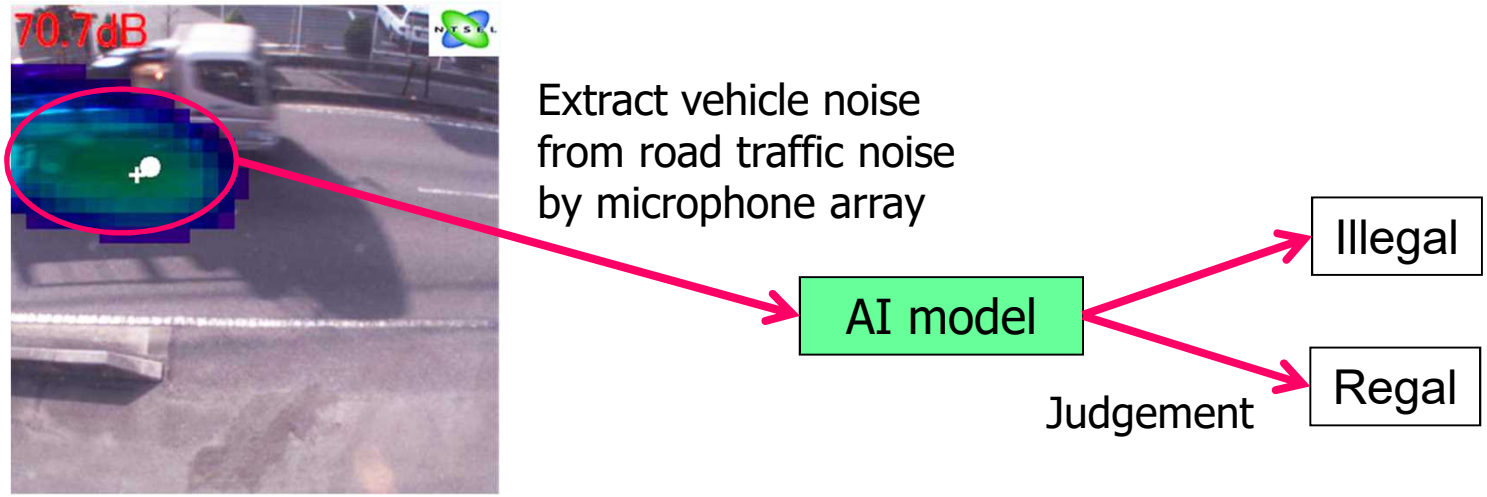
Probabilities predicted by AI model [%]			Predicted category	Result of inspection	Proximity stationary noise [dB]
Illegal	Regal	Others			
26.3	63.4	10.3	Regal	Regal	93
11.1	50.6	38.3	Regal	Illegal	99
23.0	56.3	20.7	Regal	Regal	88
1.4	98.1	0.5	Regal	Regal	87
0.1	99.9	0.0	Regal	Regal	82
67.4	18.8	13.7	Illegal	Illegal	98

- By changing training data, this method can be used in various ways.
- For example, there is a possibility that AI model can judge whether a vehicle's R41 result exceeds its limit value or not only by the vehicle's pass-by noise.

Research in progress

- Judgement method of illegal replacement muffler by using AI model has been limited to motorcycles running alone.
- The system using the microphone array can measure pass-by noise in the traffic flow separatory.
- Therefore, if AI model is applied to separated pass-by noise by using microphone array, it will be possible to identify the vehicles whose proximity stationary noise level exceeds its limit value from pass-by noise in the traffic flow.

- To archive the goal, the first step is to reduce the size of the microphone array so that it can be easily installed on the roadside.
- Since existing AI model cannot be used for microphone array, we are planning to measure new training data by using the microphone array.



Summary

- This presentation showed elemental technologies that have been established by NTSEL for developing automatic sensing system from remote location, which detects vehicles equipped with illegal replacement muffler traveling on the road.

- By using microphone array, it was shown that it is possible to measure individual vehicle's pass-by noise in real-time.

- By using AI created by deep learning, it was shown that it is possible to judge the vehicles whose proximity stationary noise level exceeds limit value from pass-by noise with high accuracy. However, the application is limited to motorcycles running alone.

- Now, NTSEL try to combine these two technologies to develop an automatic monitoring system that can measure individual vehicle’s pass-by noise from the traffic flow and automatically judge whether it is illegal replacement muffler or not.

Thank you for your attention

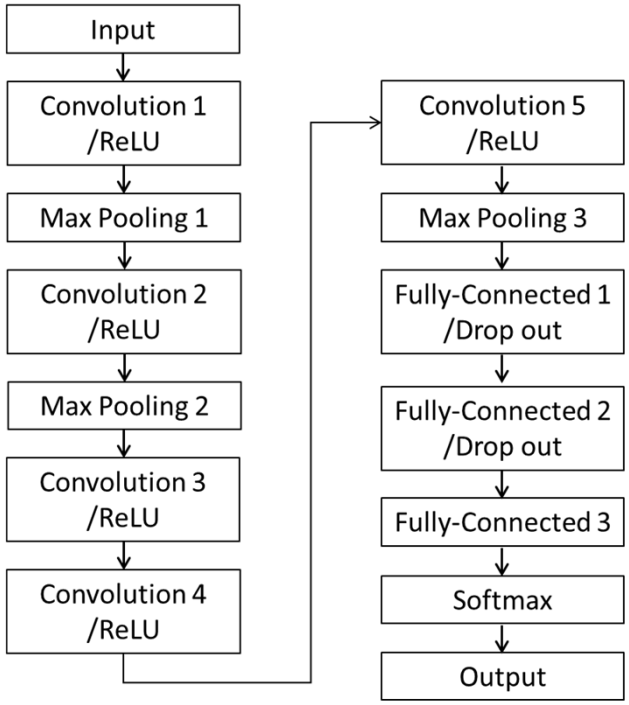
Houzu, Hiroyuki
houzu@ntsel.go.jp

---- Reference material ----

Algorithm to create AI model in this study

Deep learning : AlexNet

- Deep learning is a multi-layered neural network.
- In this research, AlexNet is used to create AI model. AlexNet consists of five convolutional layers, three fully coupled layers, a pooling layer, a dropout layer, and a softmax function.
- The dropout layer randomly sets the input to zero to prevent overlearning.
- The softmax function normalizes the output value from 0 to 1 to create it easier to understand the results.

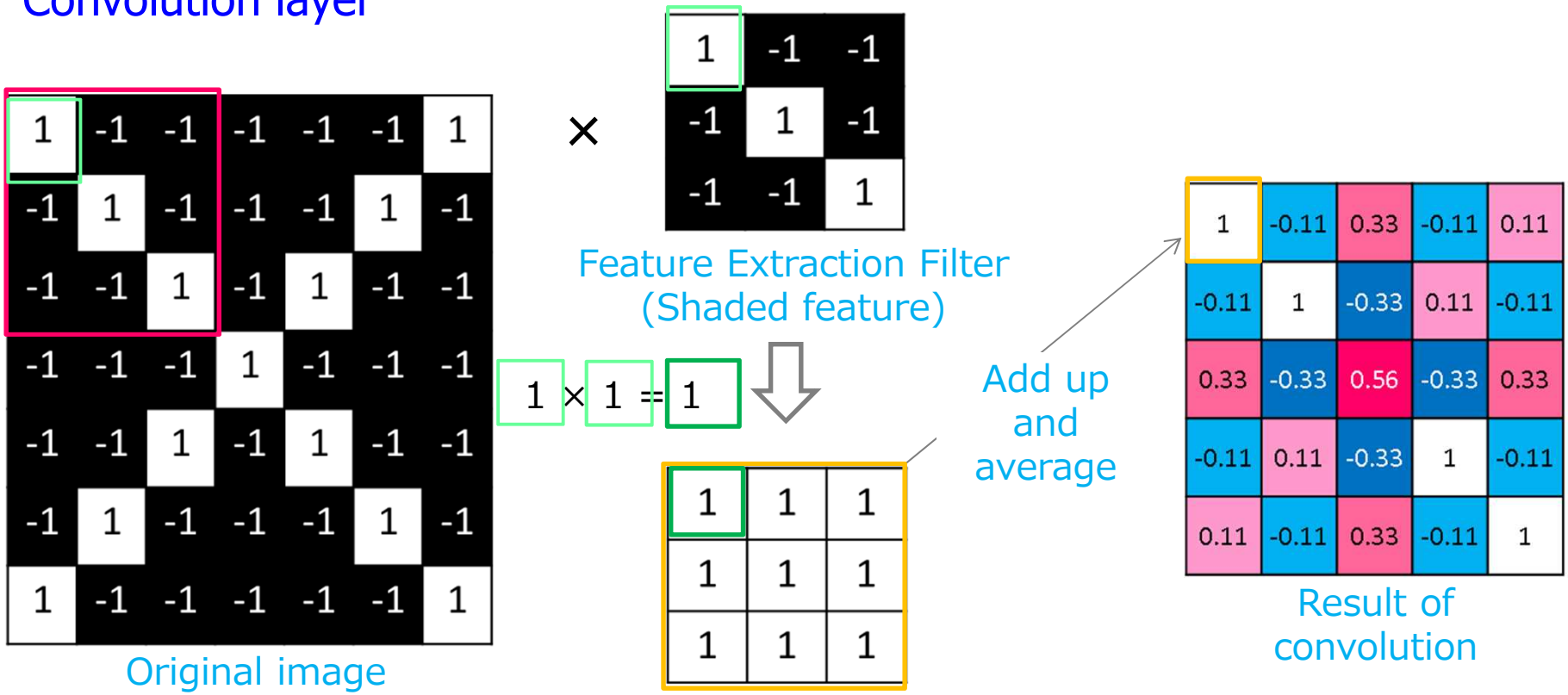


Flowchart of AlexNet

Deep neural network (DNN)

- DNN consists of convolution layer, pooling layer and fully-connected layer.

Convolution layer

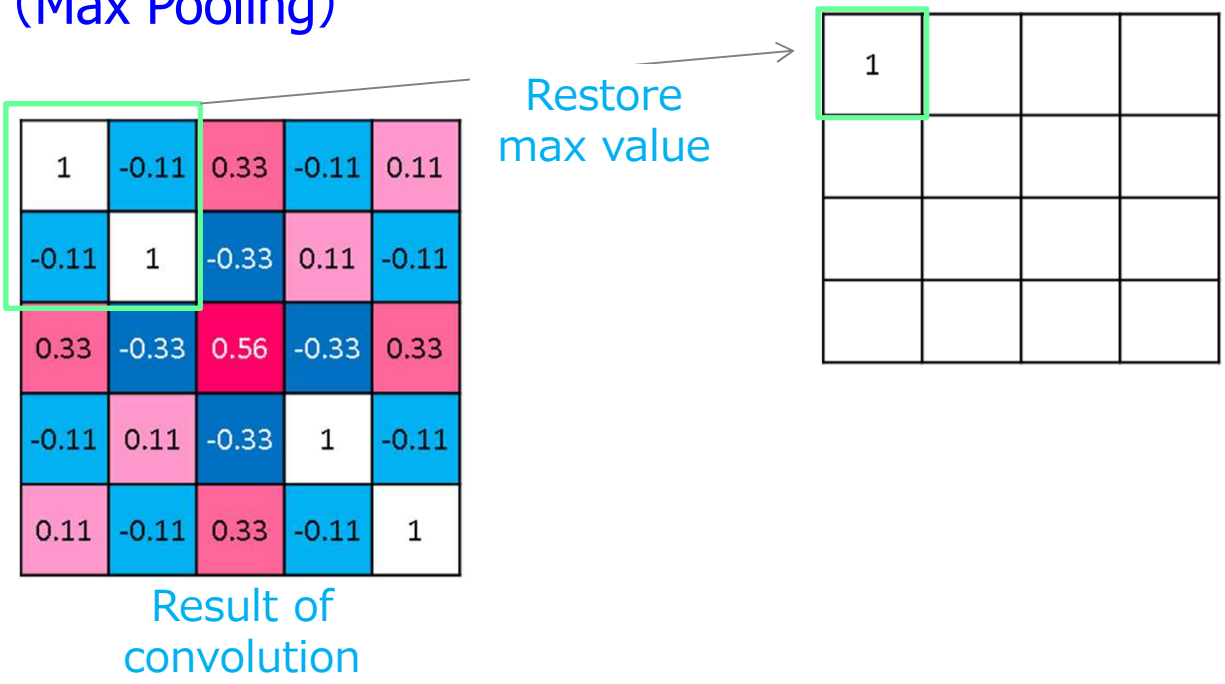


- Apply a feature extraction filter and output the value divided by the number of pixels in the filter.
- If the features match, the value is "1"; if not, the value is "-1".
- The pixels with the shaded features can be identified.

Deep neural network (DNN)

- DNN consists of convolution layer, pooling layer and fully-connected layer.

Pooling layer（Max Pooling）

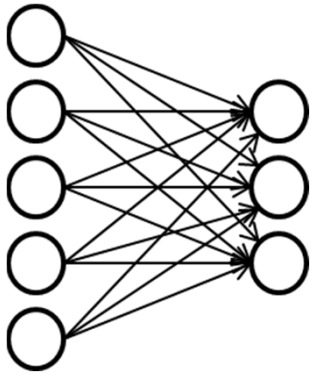


- Coarsely organize features by restoring strong feature (high value) pixels within a certain range of pixels.
- The exact location is not important because it is combined with convolution.
- Pooling layer makes the image size smaller and it leads to reduce the amount of computation.

Deep neural network (DNN)

- DNN consists of convolution layer, pooling layer and fully-connected layer.

Fully-connected layer



- Input is a two-dimensional list, and all nodes are combined (with different weightings for each node)
- Calculate the probability of each classifications.
- The classification with the higher probability becomes the final result.