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The Real-world Emissions Prediction with Deep Learning Based on the SEMS Measurement Data

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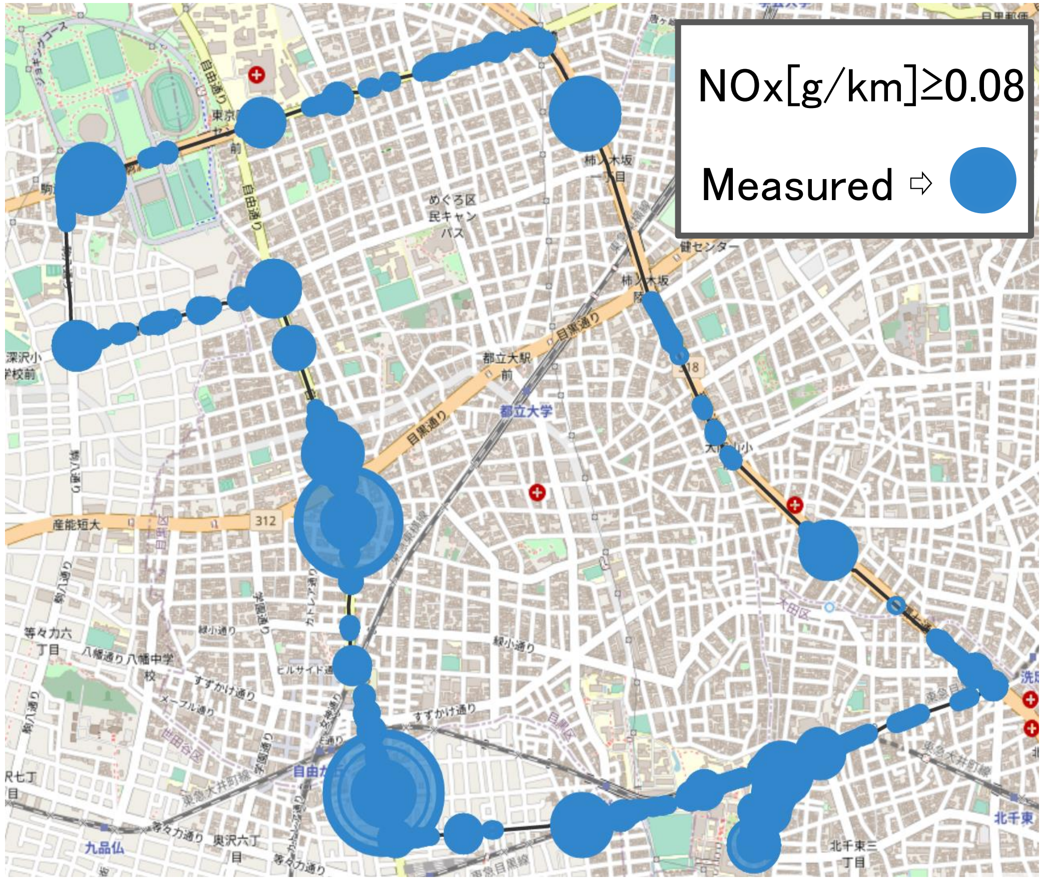
10th Annual International PEMS Virtual Conference

Research Background

- ✓ Local roadside emission → “Hot spot”
- ✓ RDE regulations using PEMS



On-road measurement data; NOx mass ≥ 0.08 g/km

PEMS measurement

Research Background

- ✓ “How much” and “Where” air pollutant are emitted?
  = “Hot Spot” or not?

- ✓ Evaluation of the roadside real-world emission using on-board emission measurement system

- ✓ In the future, there will be a need for a method of grasping the real-world emissions using only vehicle information obtained through OBD in real time without direct measurement of emissions.

⇩

For the real-world emissions evaluation,

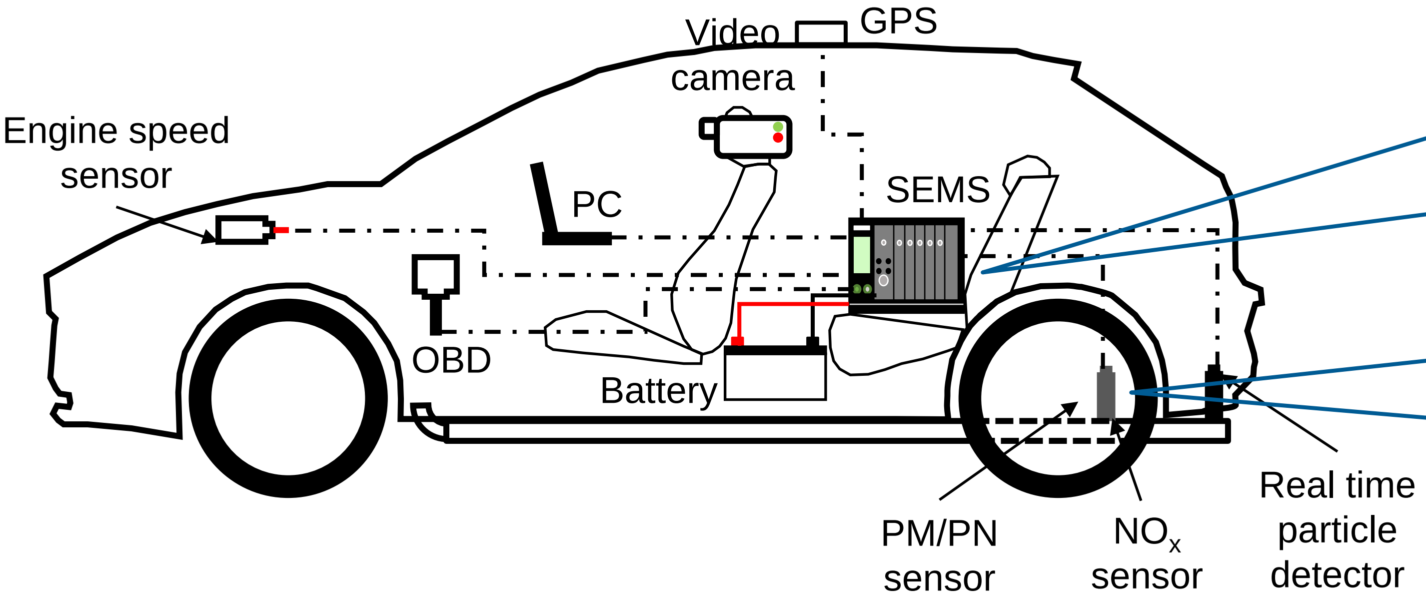
1. Analysis of emission behavior by on-road measurement on general roads and highways using diesel passenger vehicle
2. Construction and verification of emission prediction model by deep learning using vehicle information obtained by measurement

Test Vehicle

Type	Station Wagon
Riding capacity [people]	5
Length [m]	4.06
Width [m]	1.69
Height [m]	1.50
Wight [kg]	1220
Engine type	L-4 DOHC Diesel Engine
Displacement [L]	1.49
Compression ratio	14.8
Fuel supply system	Common-rail Fuel Injection
Aftertreatment system	DOC, DPF
Adapted emission regulation	Japan 2009 Regulation: NO_x < 0.08 g/km
Fuel consumption saving	Stop idling system

On-road Driving Test Setup

✓ Sensor-based Emissions Measurement System



SEMS
(NCEM, NGK Spark Plug)

NOx Sensor
(NOx, O_2)

✓ Measurement Items

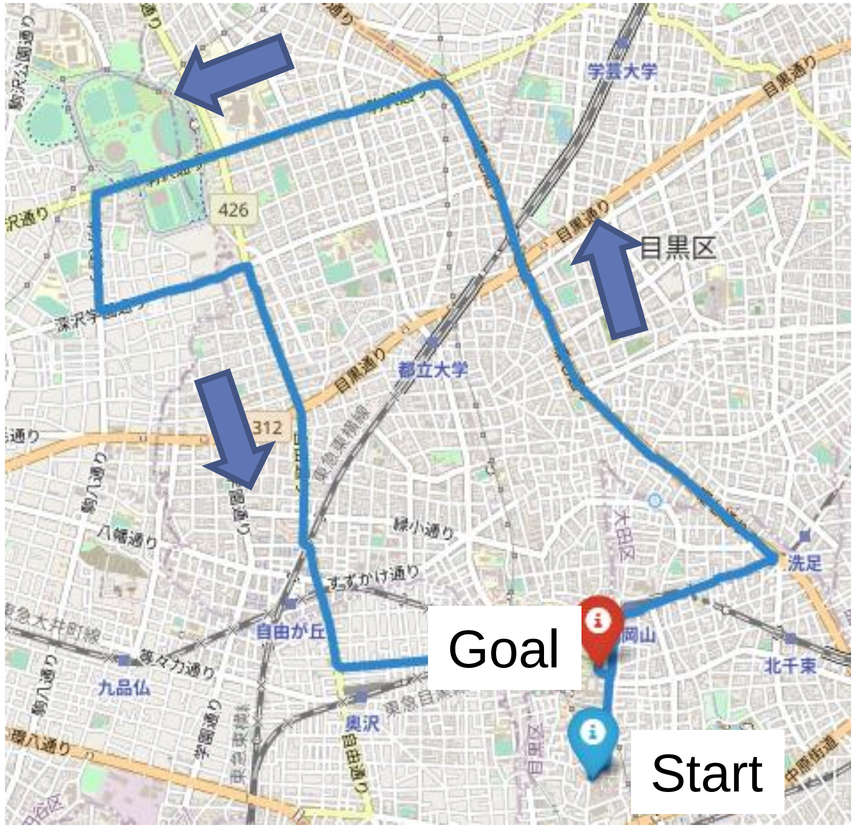
NOx conc., O_2 conc. (→ CO_2 conc. Calculation)*, OBD information, GPS, traffic situation

* S. Sato, et al, "Real-World Emission Analysis Methods Using Sensor-Based Emission Measurement System", SAE paper 2020-01-0381 (2020)

On-road Driving Test Routes

On-road driving tests: 79 times, general road & highway

	Route Number	Number of runs	Distance [km]
General road	Route 1	45	9.664
	Route 2	4	8.935
	Route 3	15	9.761
	Route 4	1	3.209
	Route 5	1	2.244
General road & Highway	Route 6	3	30.063
	Route 7	3	23.464
	Route 8	2	40.931
	Route 9	3	30.289
	Route 10	1	37.081
	Route 11	1	13.133



Route 1

On-road Test Routes

	Route Number	Number of runs	Distance [km]
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Route 11

For deep learning, the measurement data of Route 1 – 10 were used for the learning, the data of Route 11 was used for the validation.

Hot Spot Analysis

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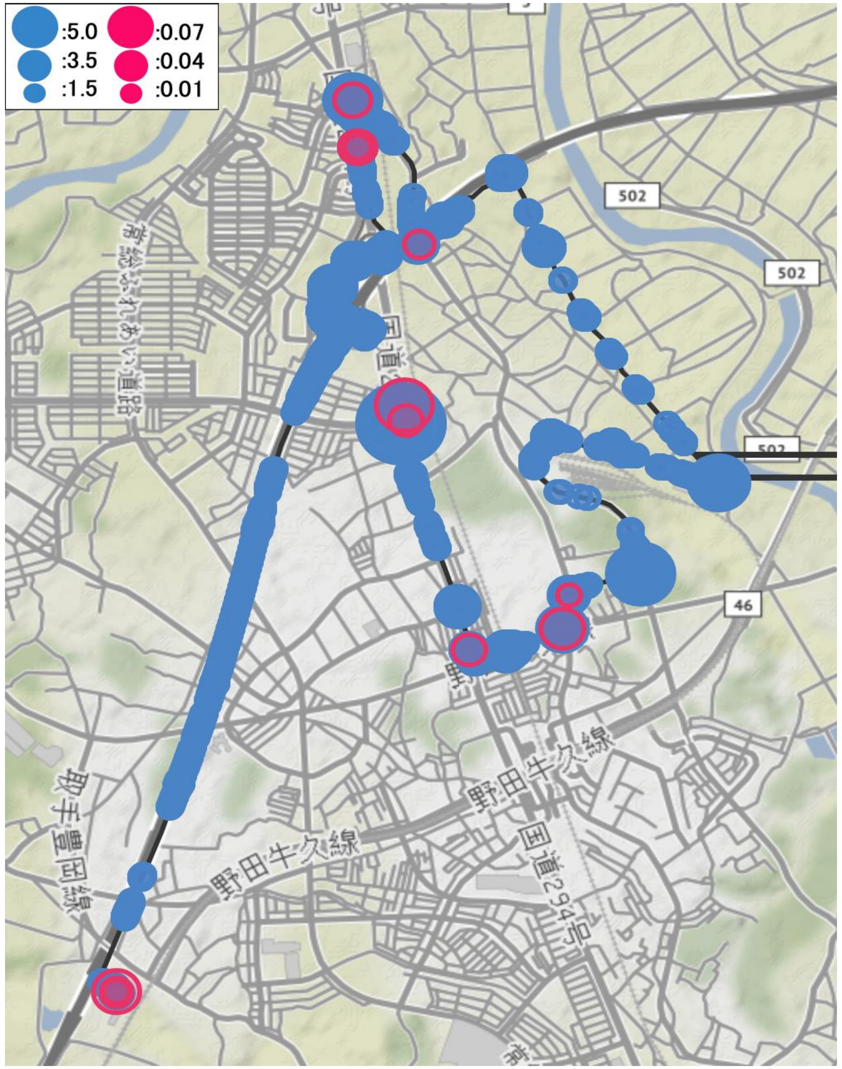
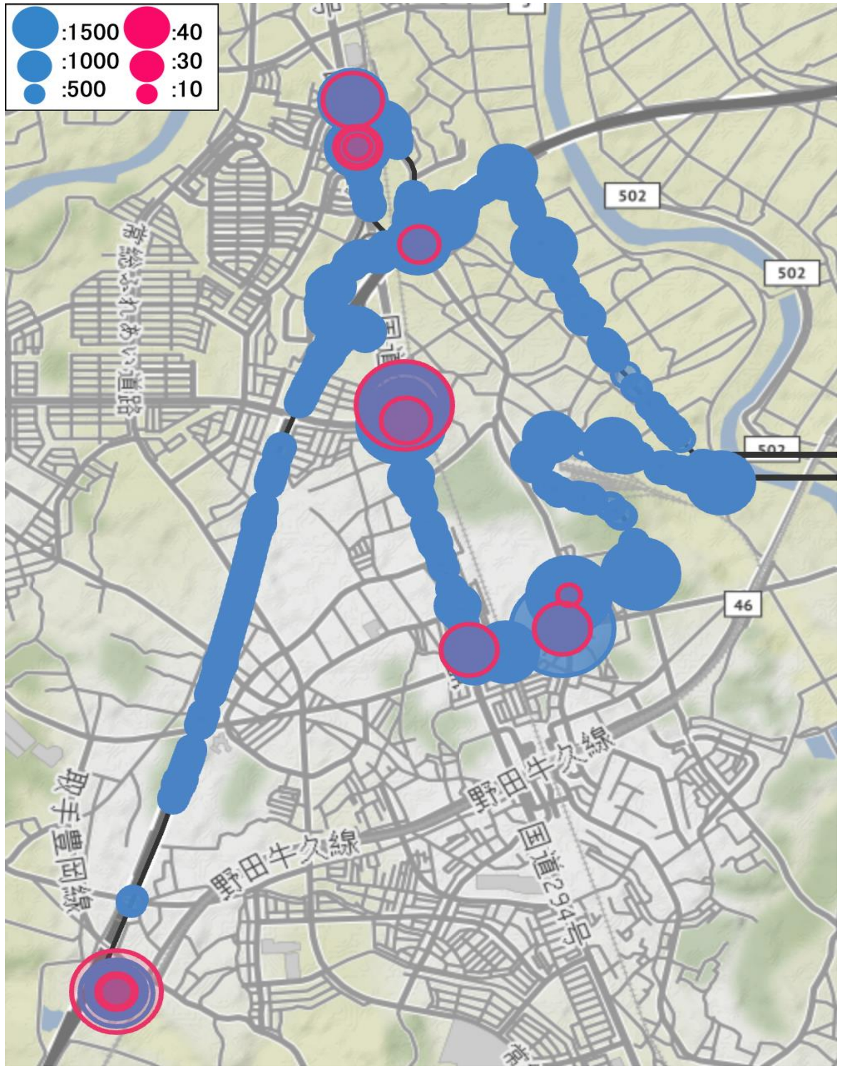
Driving [g/km]
Stop [g]

✓ $E_{NOx,x} \geq 0.05$ g/km, $E_{CO2,x} \geq 100$ g/km

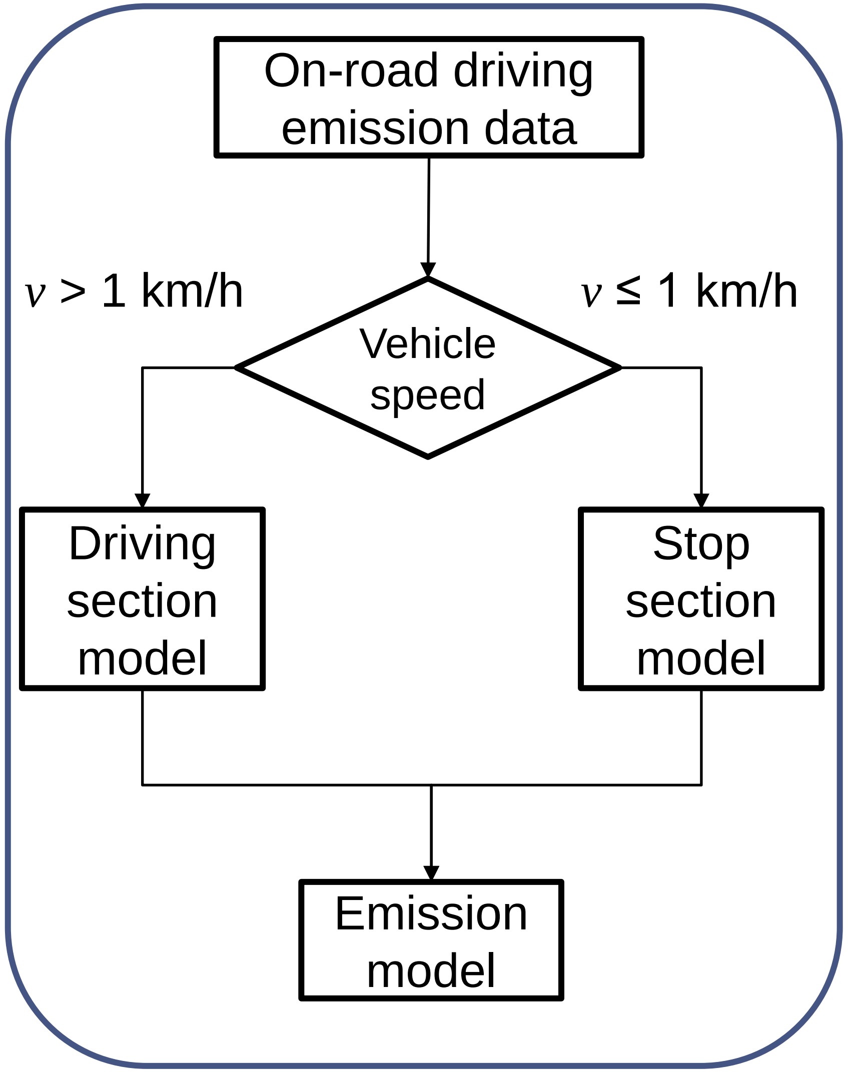
NOx



CO_2



Emission Prediction Procedures



✓ Stop section model

Prediction using non-linear regression equation for each engine speed classification

- Clustering by Dynamic Time Warping (DTW) & k-means methods
- Support Vector Regression (SVR)

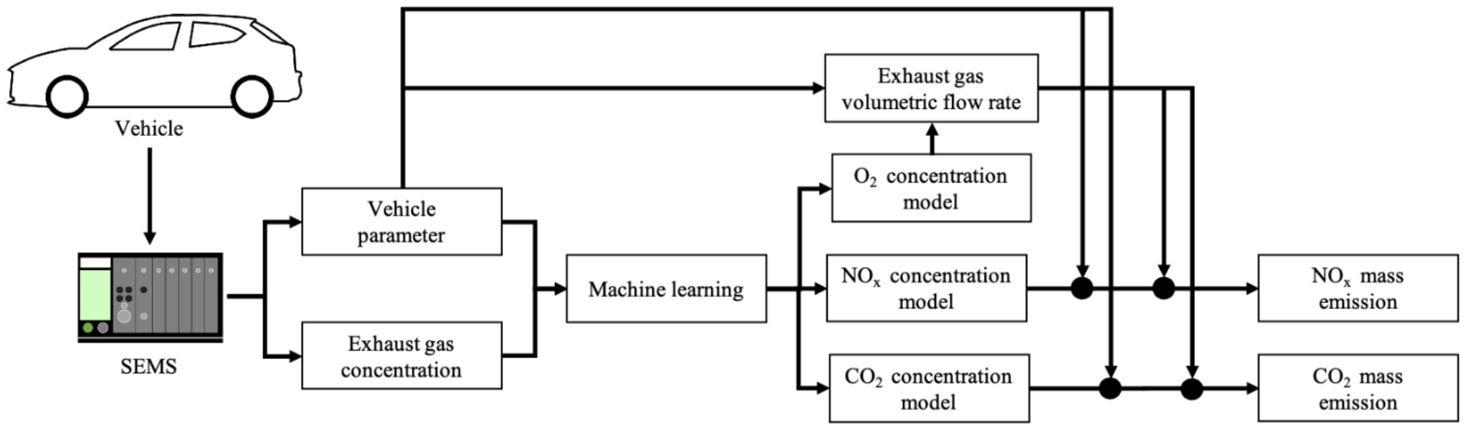
✓ Driving section model

Prediction using a time series prediction model by deep learning

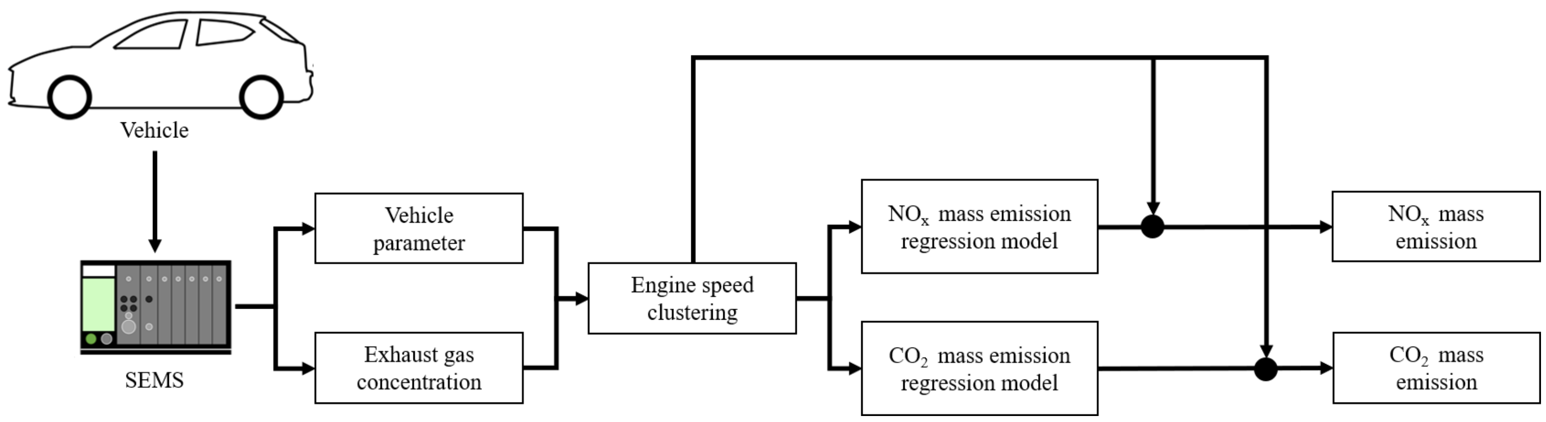
✓ Prediction models for NOx and CO_2 emissions

Emission Prediction Flow

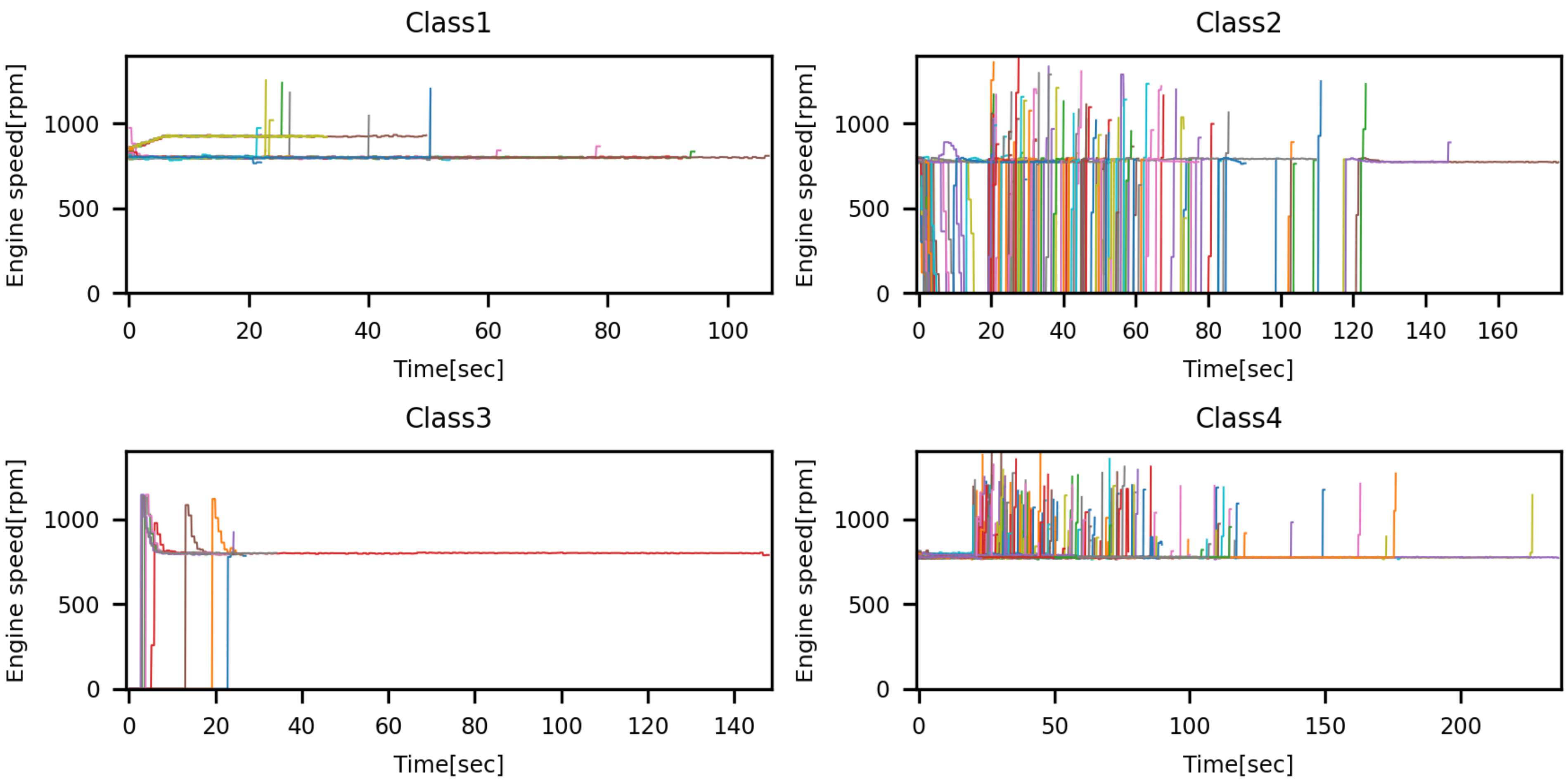
✓ Driving section prediction



✓ Stop section prediction



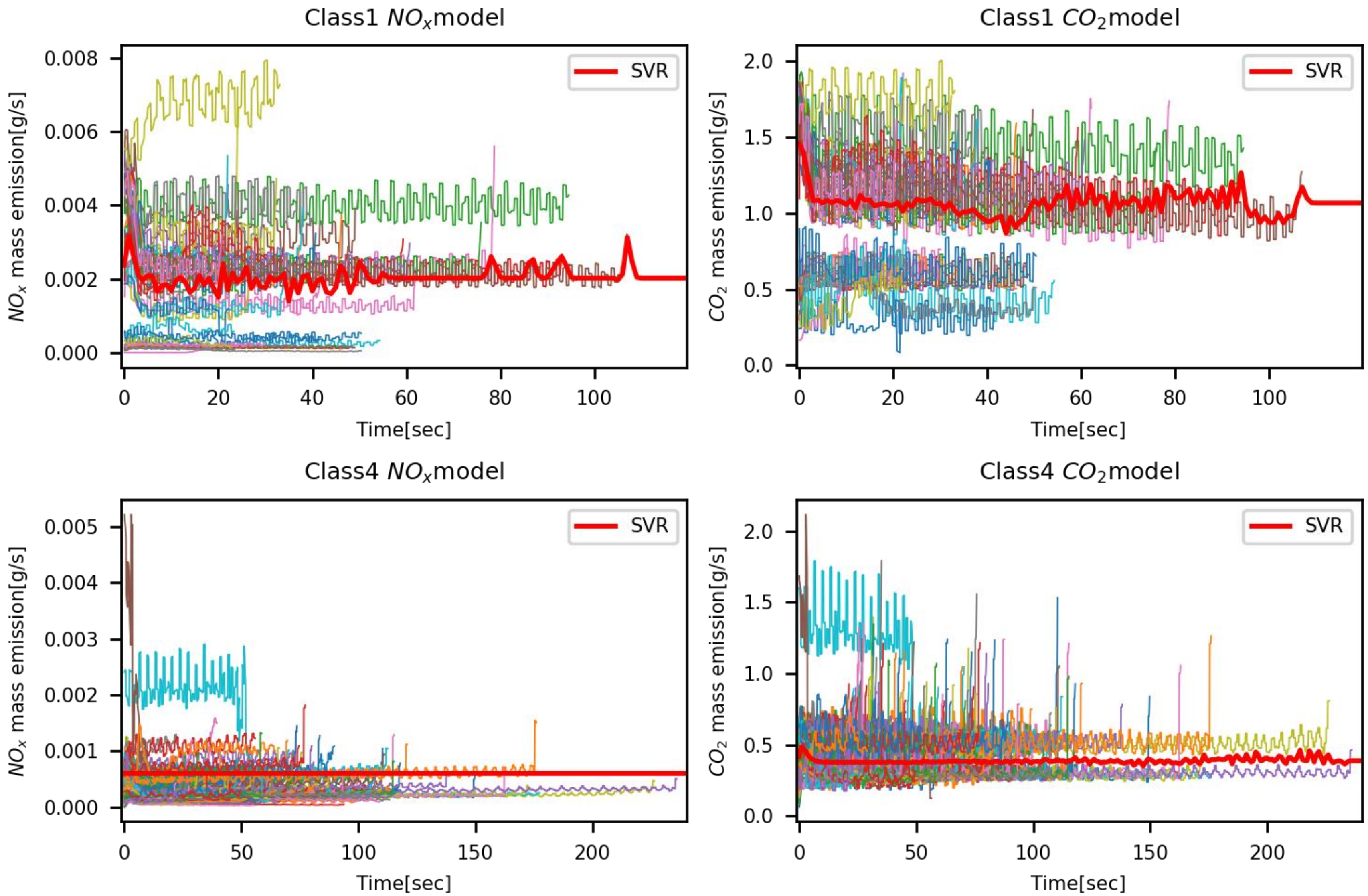
Stop Section Model



- ✓ Class 1 & 4: Mass emission calculation with non-linear regression
- ✓ Class 2 & 3: Calculated as no idling and mass emissions of 0 g/s

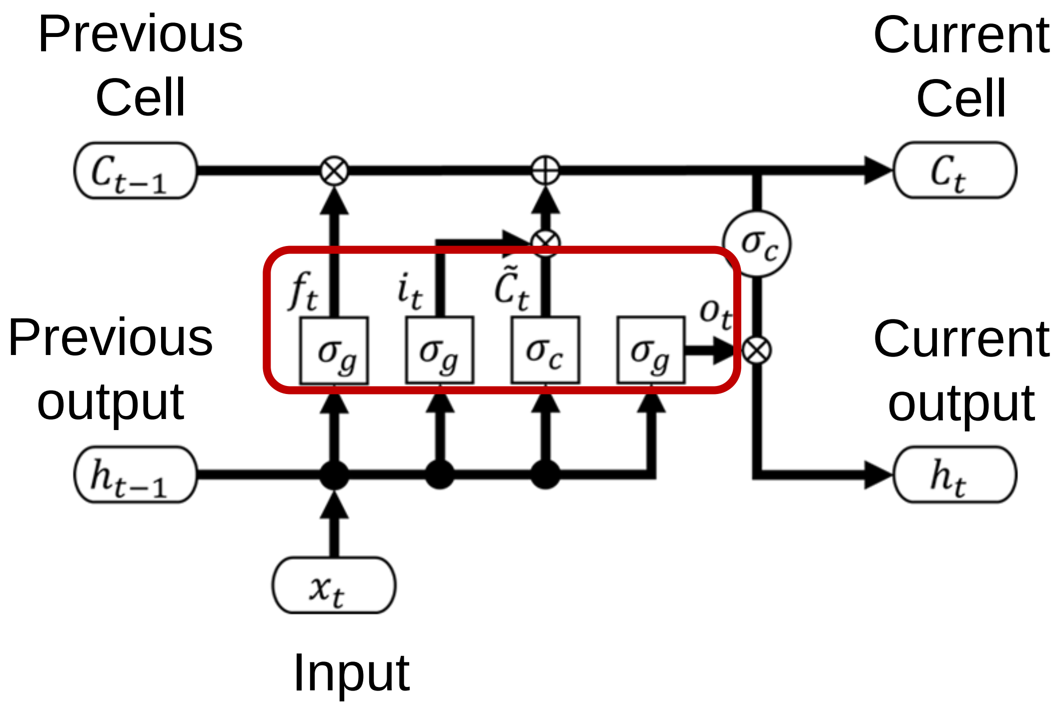
Stop Section Model

NOx | CO_2



Driving Section Model: LSTM

Deep learning with "Long Short-Term Memory" [Hochreiter, S. et al., 1997]



✓ Predictable in long-term time series by selecting information used for learning

LSTM Network, Learning Parameters

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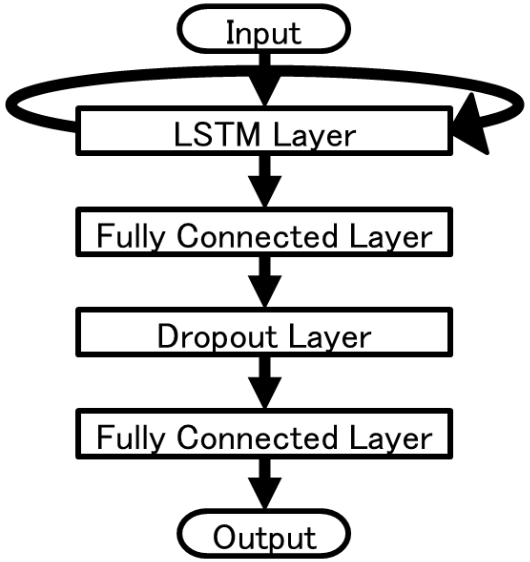
- Deep learning network



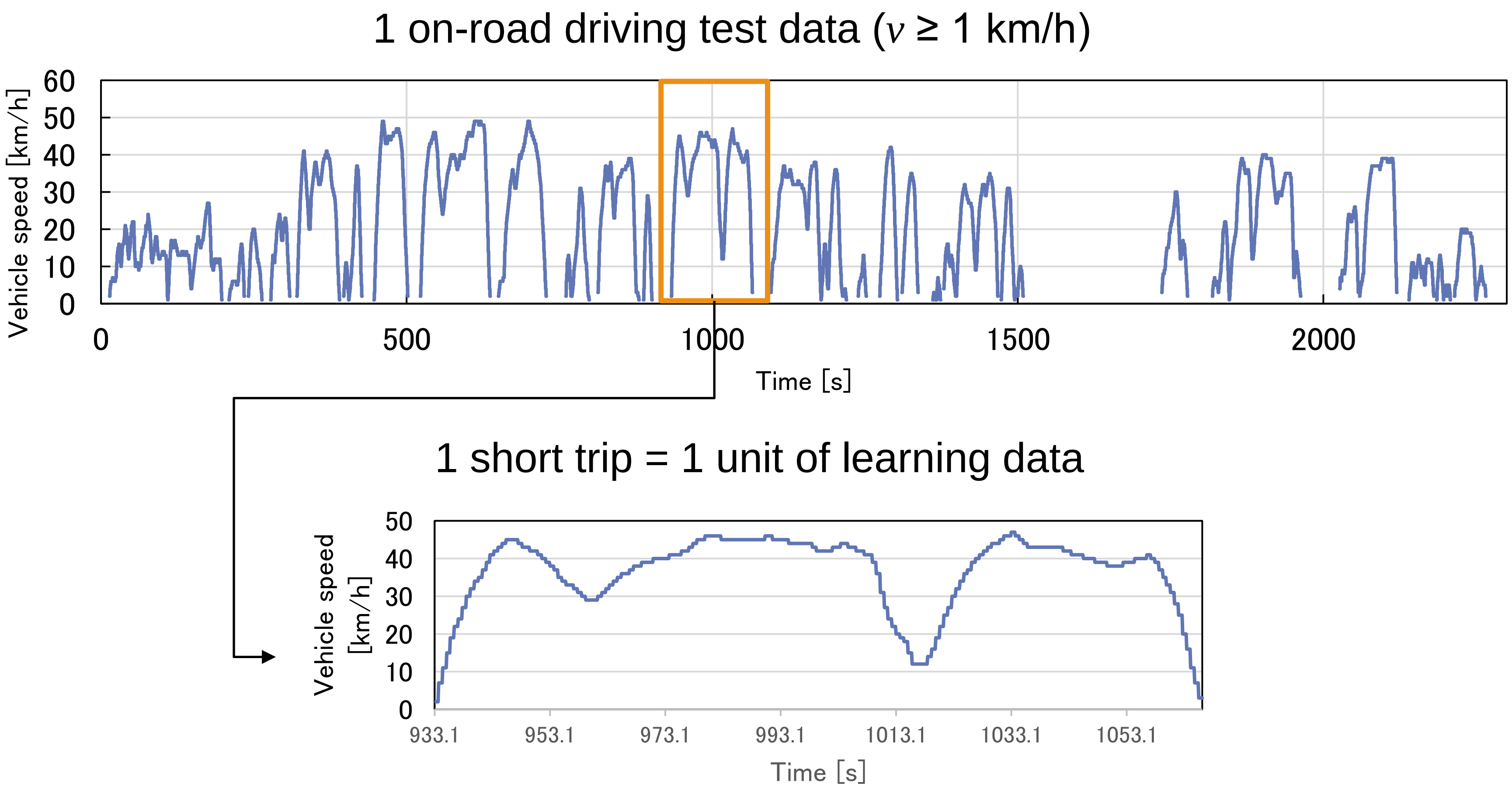
Layer	Option
Sequence Input Layer	12 Parameter Input
LSTM Layer	500 Hidden Unit
1st Full Connected Layer	400 Output Size
Dropout Layer	0.5 Dropout Ratio
2nd Full Connected Layer	1 Output Size

- Learning parameters

Behavior	Parameter
Engine	Engine Speed [rpm]
	Mass Air Flow Rate [g/s]
	Engine Load Value [%]
	Throttle Position [%]
	Fuel Rail Pressure [kPa]
	Intake Manifold Absolute Pressure [kPa]
	Fuel Injection Timing [rad]
	Engine Coolant Temperature [℃]
	Intake Air Temperature [℃]
Vehicle	Vehicle Speed [km/h]
	Acceleration [m/s]
Driver	Pedal Position [%]

Driving Section Model: Short Trips

✓ 2041 short trips data obtained from 77 on-road driving data



✓ In the section where the short trip is long (300 sec or more), the data is divided into 20 (highway driving data).

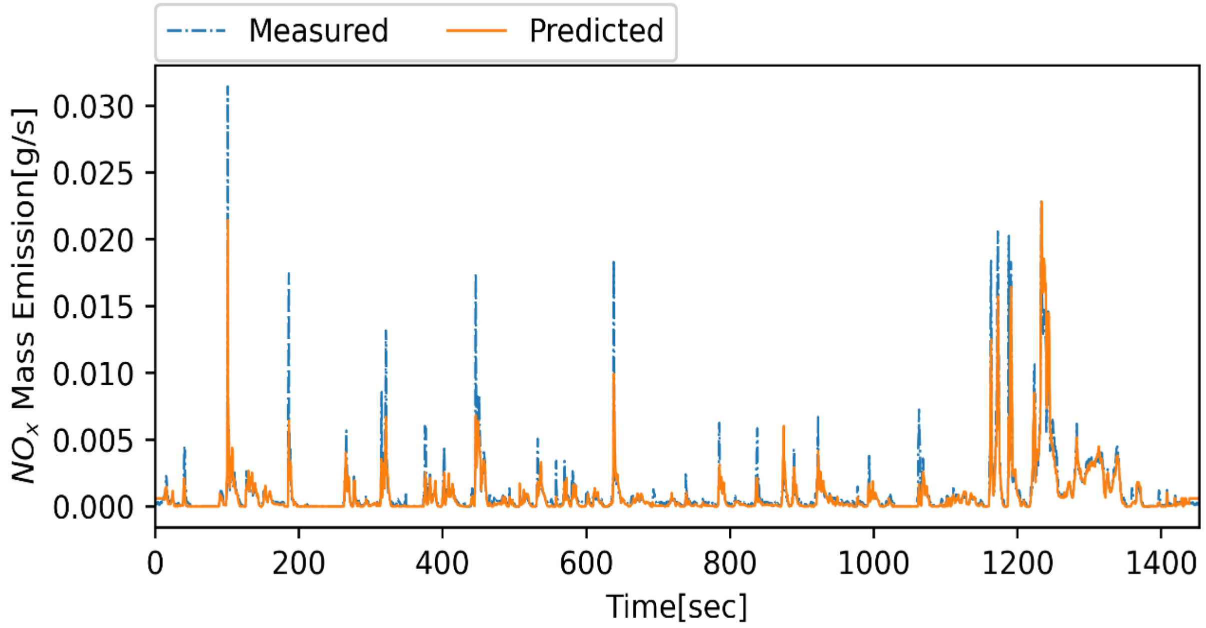
Prediction Results

NOx

- Route-averaged mass emission

Measured : 15.0 g/s
Predicted : 12.4 g/s
Error 17.1%

- Time series

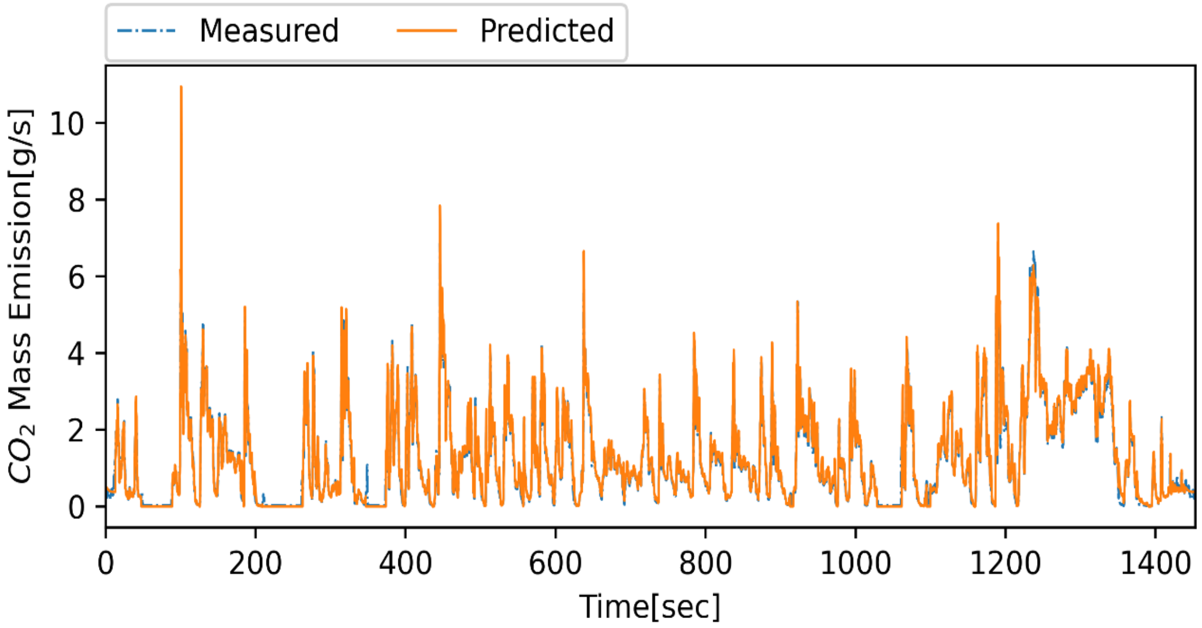


CO_2

- Route-averaged mass emission

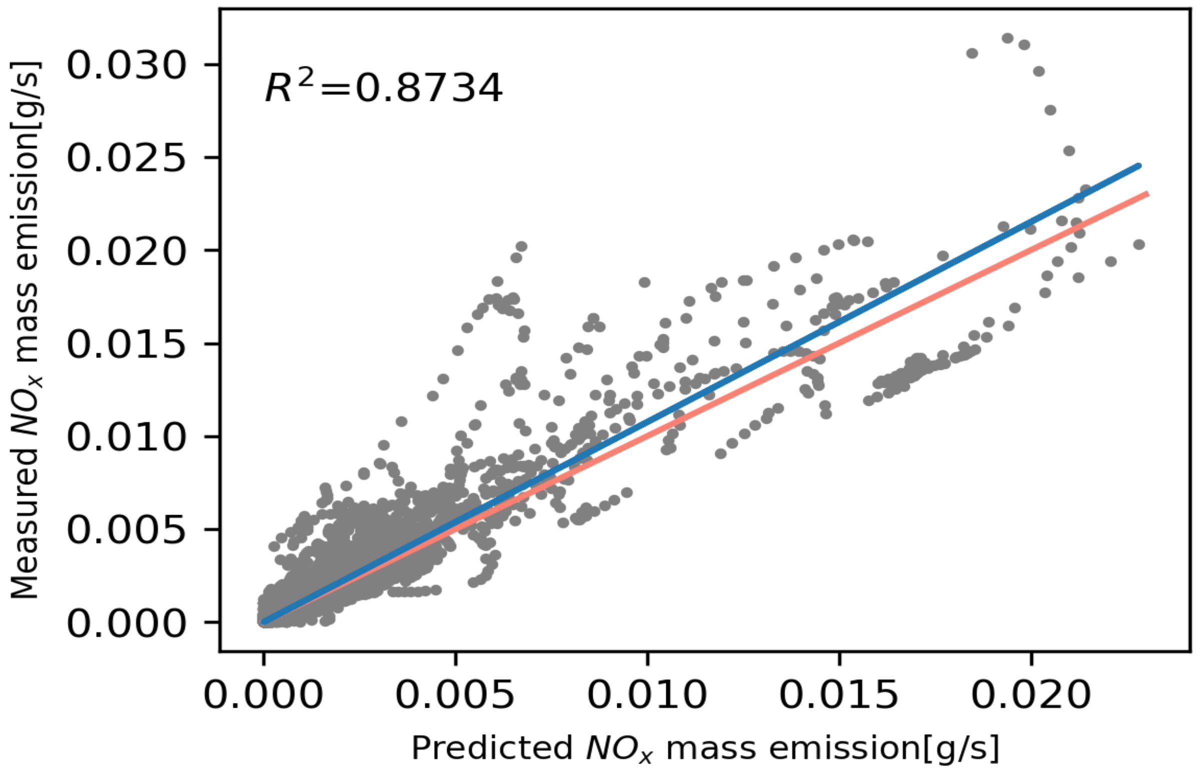
Measured : 17908.9 g/s
Predicted : 18518.6 g/s
Error 3.4%

- Time series

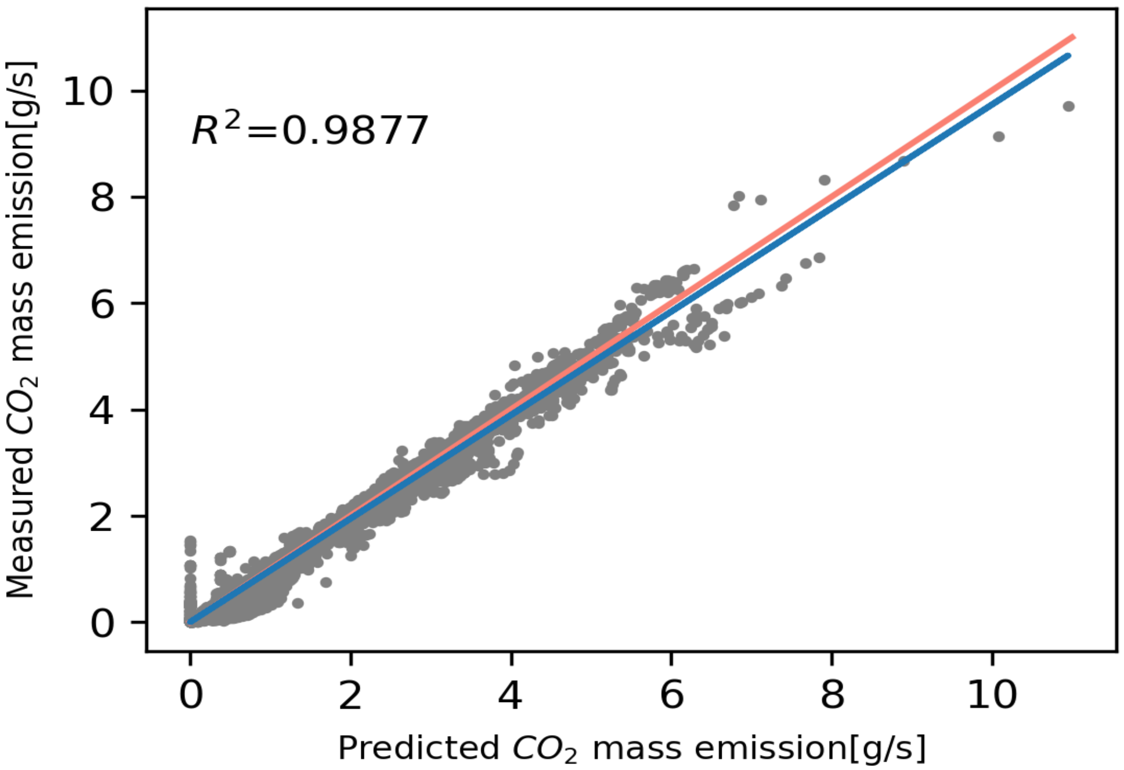


Prediction Results

NOx



CO_2



Summary

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1. Large amount of NOx and CO_2 were emitted when the speed fluctuation of the vehicle becomes large and the acceleration / deceleration changes.

2. A prediction model of real-world emissions using deep learning was constructed.

3. When a verification route consisting of general roads and highways was predicted, the relative error due to the total value of the mass emission for the entire route was 17.1% for NOx and 3.4% for CO_2. While the CO_2 emission prediction model can predict with high accuracy, the NOx emission prediction model shows a deviation from the measured value when NOx emission largely emitted.

4. We are conducting real-world emission analysis of direct-injection gasoline vehicle. A model is constructed to predict the emission behavior of NOx, NH_3, CO_2, and PM / PN.

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Thank You for Your Listening

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