FULLY-NEURAL APPROACH TO HEAVY VEHICLE DETECTION ON BRIDGES USING A SINGLE STRAIN SENSOR

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INTRODUCTION

ACCUMULATED VEHICLE LOADS ON BRIDGES

- may destroy gradually more than 700,000 road bridges in Japan.
- must be collected automatically for structural health monitoring.

Law enforcement

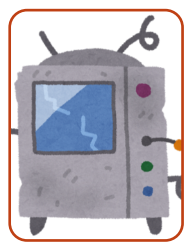
Health monitoring

PAVEMENT WEIGH-IN-MOTION (P-WIM)

- is installed on the pavement surface somewhere in the road network.
- estimates axle loads and collect evidence without stopping vehicles.

Installation

- is too expensive,
- requires pavement work.

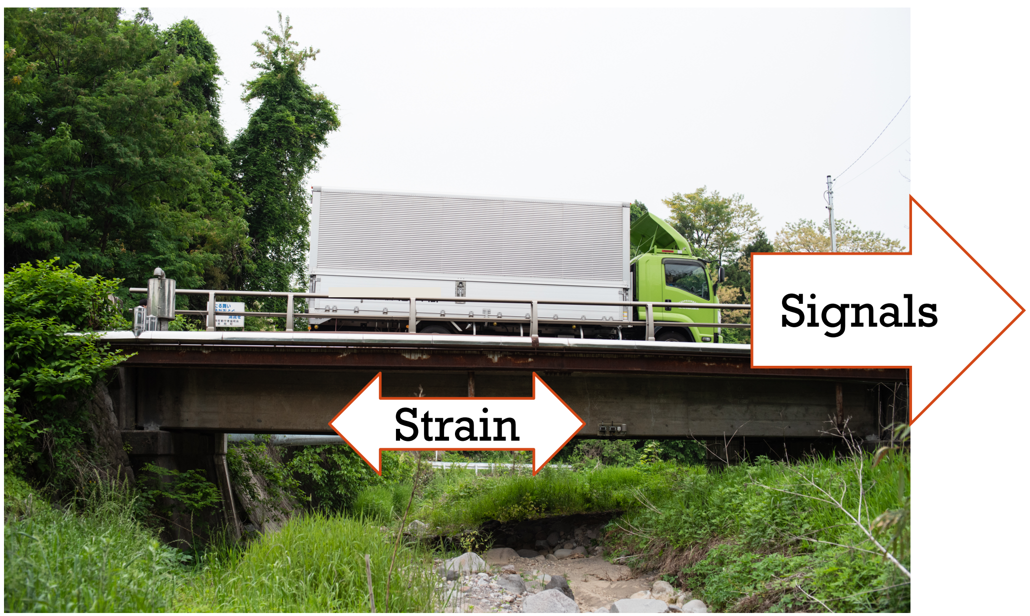


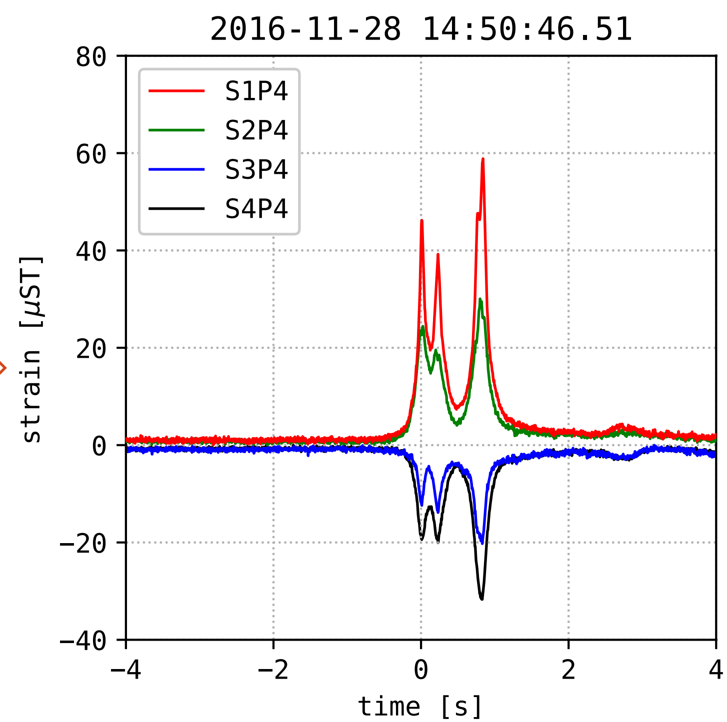
Maintenance

- break down frequently,
- bridge must be closed.

BRIDGE WEIGH-IN-MOTION (B-WIM)

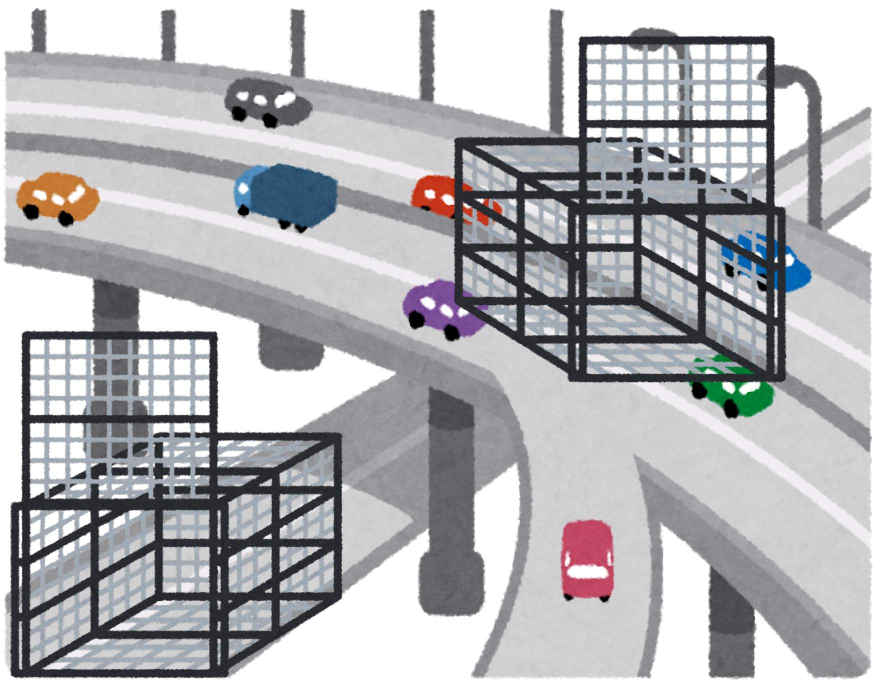
- exploits bridge components, e.g., main girders, as weighing scales.
- Peak values of the strain responses contain axle load information:





COMPLEMENTARITY: P-WIM AND B-WIM

- to capture overloaded vehicles making a detour to avoid P-WIMs,
- so that no vehicles running in the road network can break the law:



P-WIMs

- high accuracy,
- serve as supervisors.

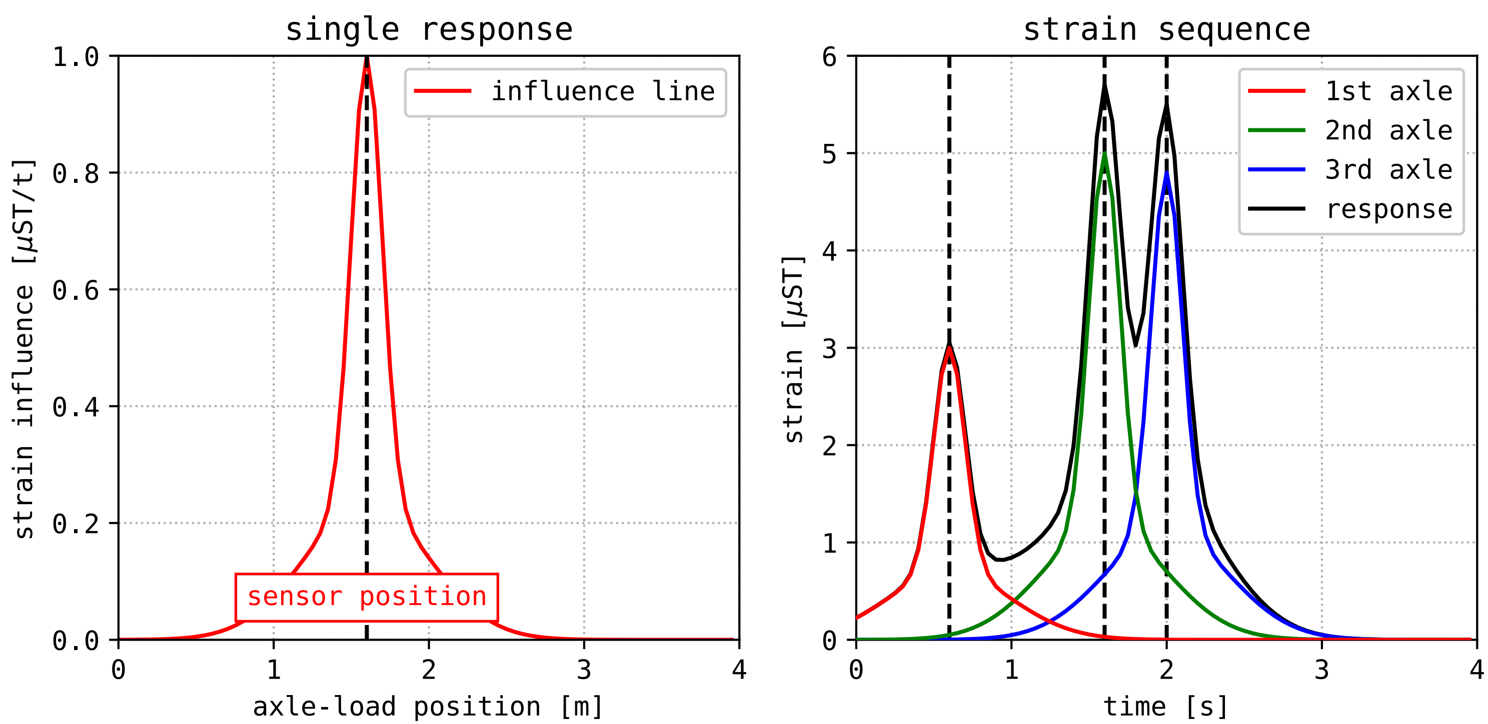
B-WIMs

- are inexpensive,
- improve accuracy.

CONVENTIONAL B-WIM

B-WIM: KERNEL-FITTING APPROACH

- estimates axle loads by fitting a unit response to the strain signal:
- The unit response is called 'influence line', unique to each bridge.



B-WIM: AREA-BASED APPROACH

- kernel fitting requires axle positions; sometimes difficult to obtain.
- Gross weight W is calculatable from product of area A and speed v:

$$\mathrm{s}(t) = \sum_{n=1}^{N} w_n i(vt - l_n),$$

s(t): raw strain sequence in time domain,
i(x): influence line, N: number of axles,
l_n: n-th axle position, w_n: n-th axle load.

$$\mathrm{A} = \int_{-\infty}^{\infty} s(t)dt = \sum_{n=1}^{N} w_n \int_{-\infty}^{\infty} i(vt - l_n)dt. = \frac{W}{v} \int_{-\infty}^{\infty} i(x - l_n)dx.$$

constant value

- Area-based approach is easier and widely applied to many bridges.

DIFFICULTY OF STRAIN MEASUREMENT

- B-WIM utilizes multiple strain sensors for accurate load estimation:
- It takes time and effort to install many strain sensors on the bridge.

Strain sensors

Decks

- lane,
- speed, etc.

Girders

- axle loads.

PARAMETER SENSITIVITY OF INFLUENCE LINE

- may degrade the accuracy of the axle-load estimation via B-WIM.
- B-WIM must consider accurate vehicle movement on the bridge:

Running positions

- change kernel shape,
- is frequently ignored.

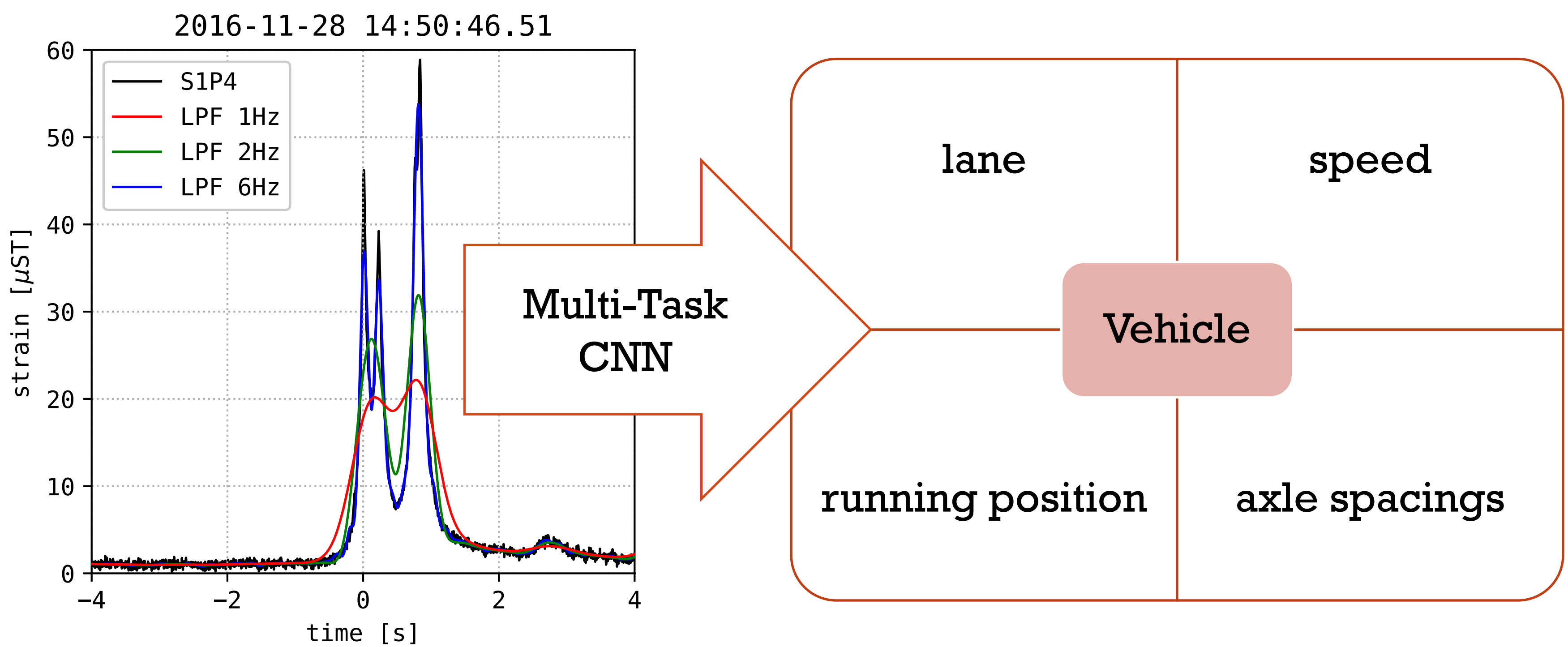
Acceleration

- changes kernel width,
- is difficult to measure.

PREVIOUS WORK IN 2019

PREVIOUS WORK: DEEP-SENSING APPROACH

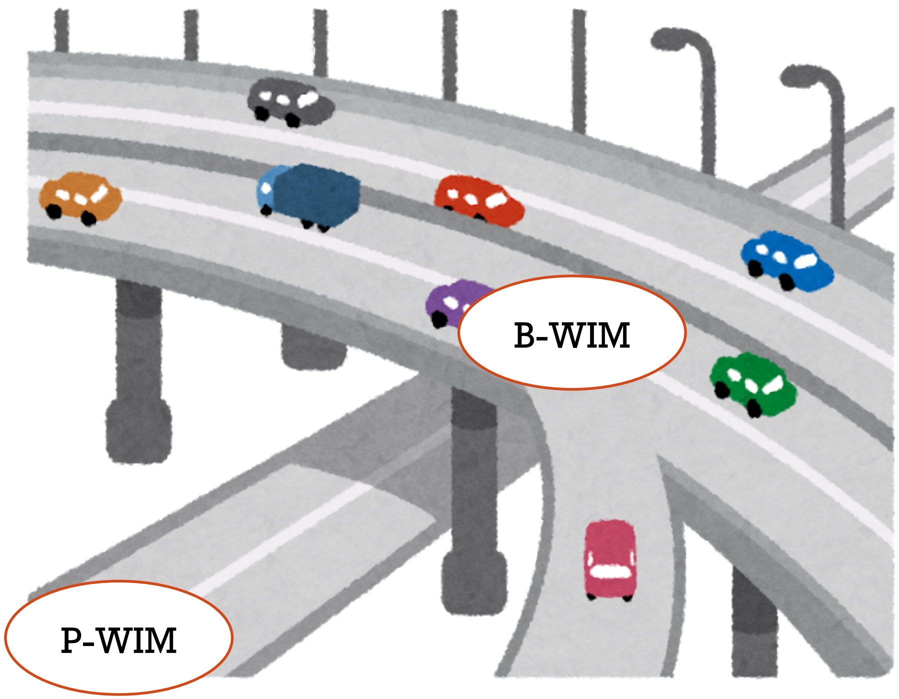
- was proposed as a single-sensor vehicle detector for B-WIM in 2019.
- detected vehicles and their properties using a single strain sensor.



FULLY-NEURAL B-WIM

CONCEPT: TRAINING B-WIMS USING P-WIMS

- P-WIMs provide B-WIMs with vehicle IDs with known axle loads.
- B-WIMs learn influence lines by using the axle load information.



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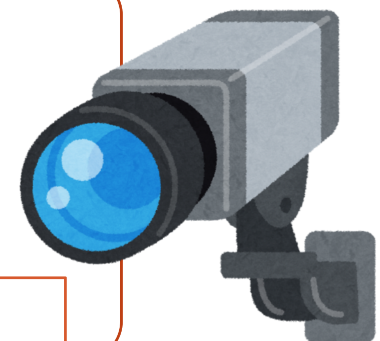


P-WIMs

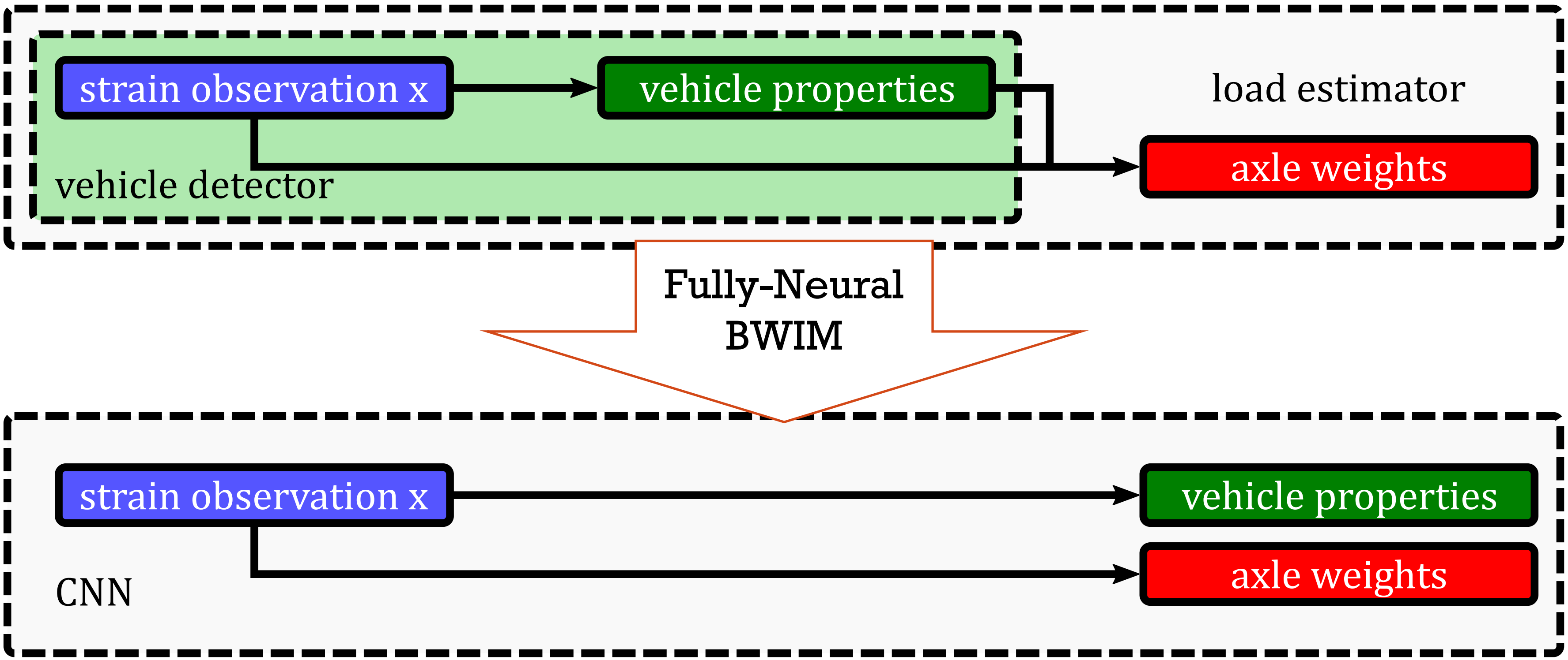
- detect heavy vehicles,
- extract features from video data,
- for vehicle reidentification (Re-ID).

B-WIMs

- retrieve load data by vehicle Re-ID,
- learn responses to known vehicles,
- predict loads for unknown vehicles.

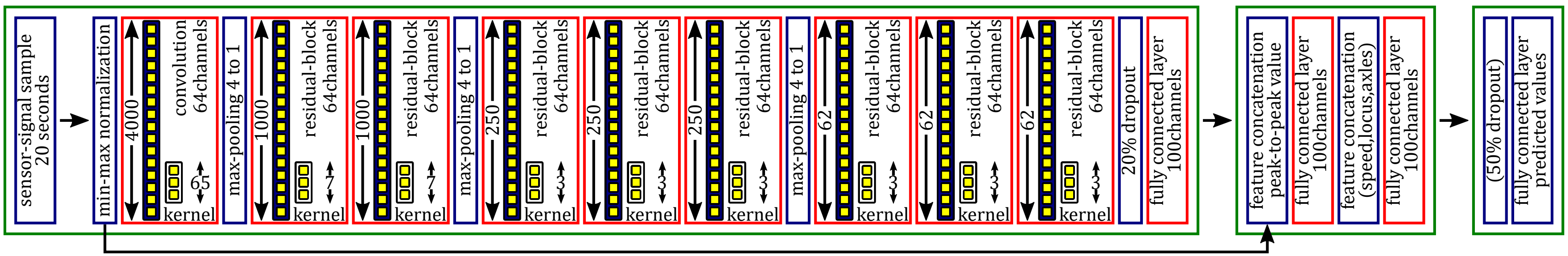
PROPOSAL: FULLY-NEURAL B-WIM

- CNN as a vehicle detector and load estimator in a multi-task fashion:

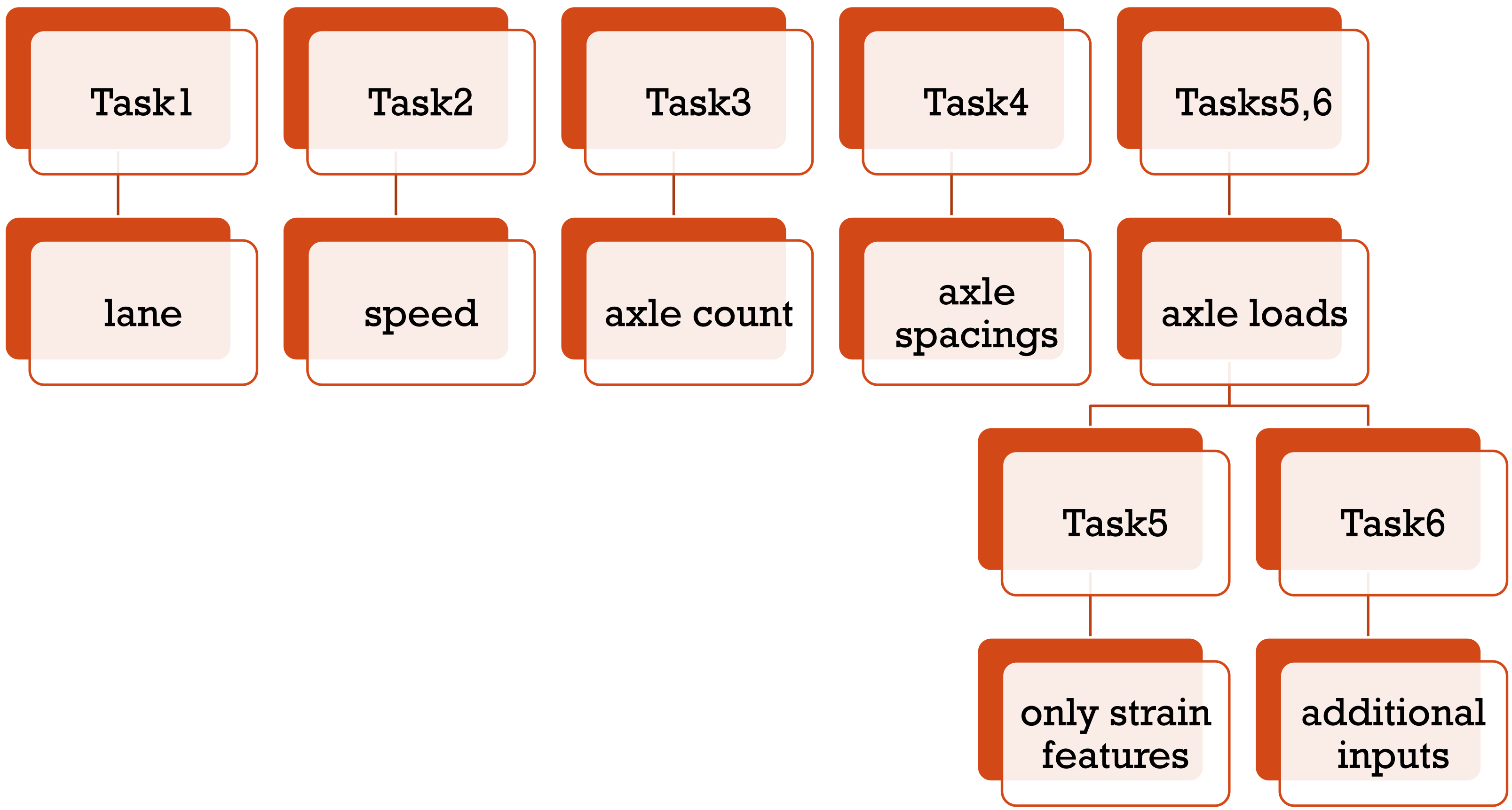


NEURAL NETWORK ARCHITECTURE

- Residual CNN; 1 convolution, 8 plain residual blocks, 3 linear layers:



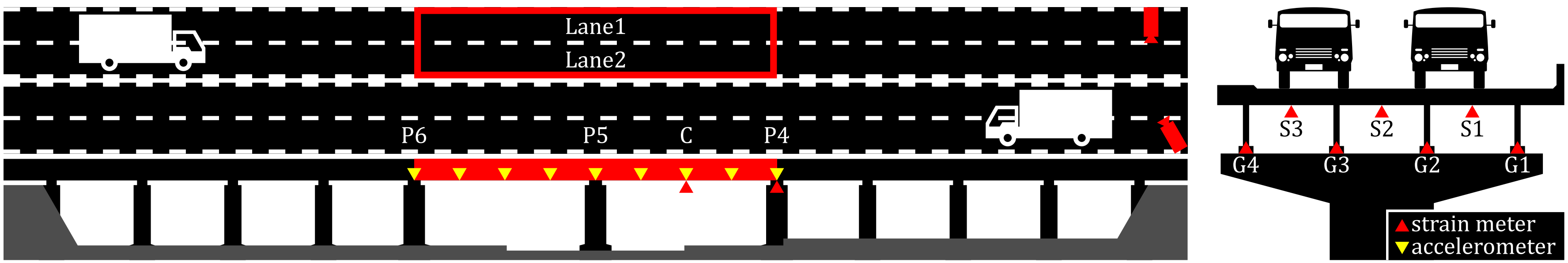
6 PREDICTION TASKS



EXPERIMENTAL RESULTS

EXPERIMENTAL SETUP

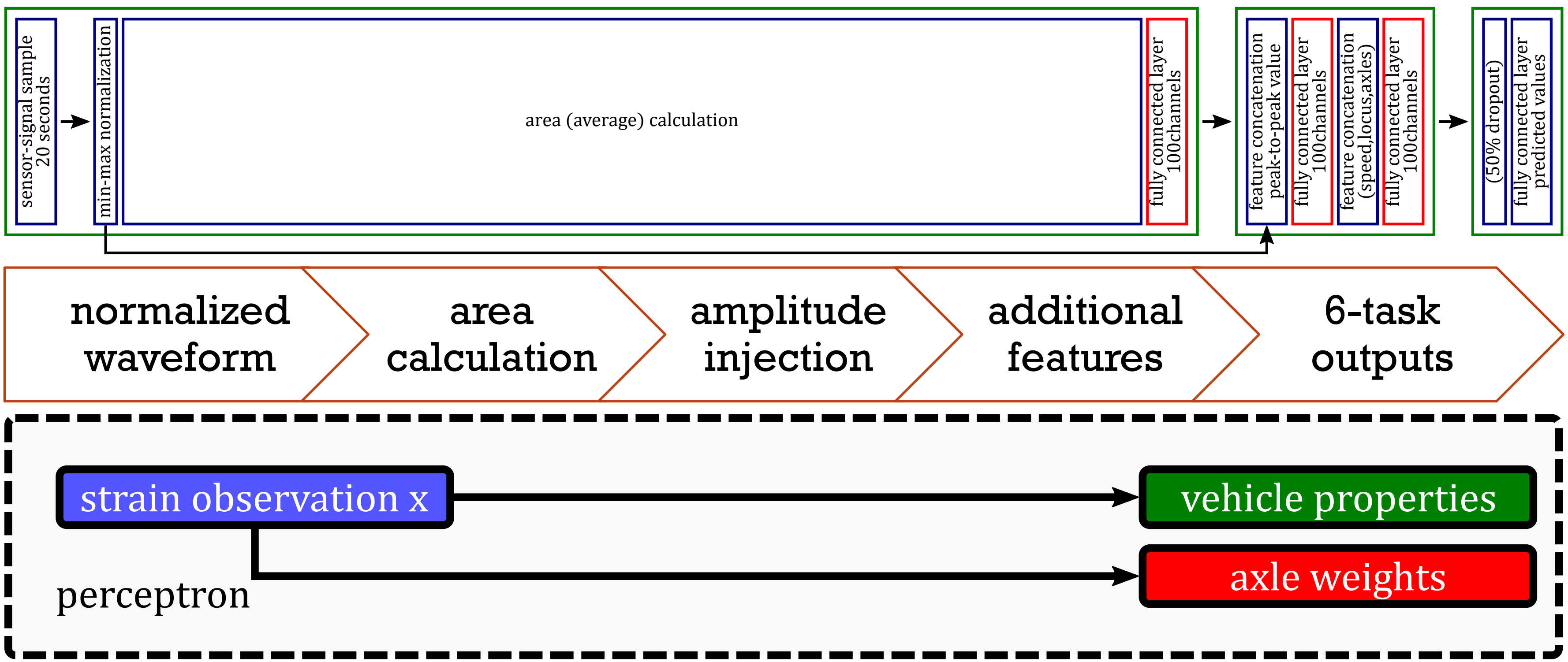
- 11 strain sensors, 2 cameras on a steel bridge in an expressway:
- We retrieved 5,923 heavy vehicles with known axle loads by Re-ID.



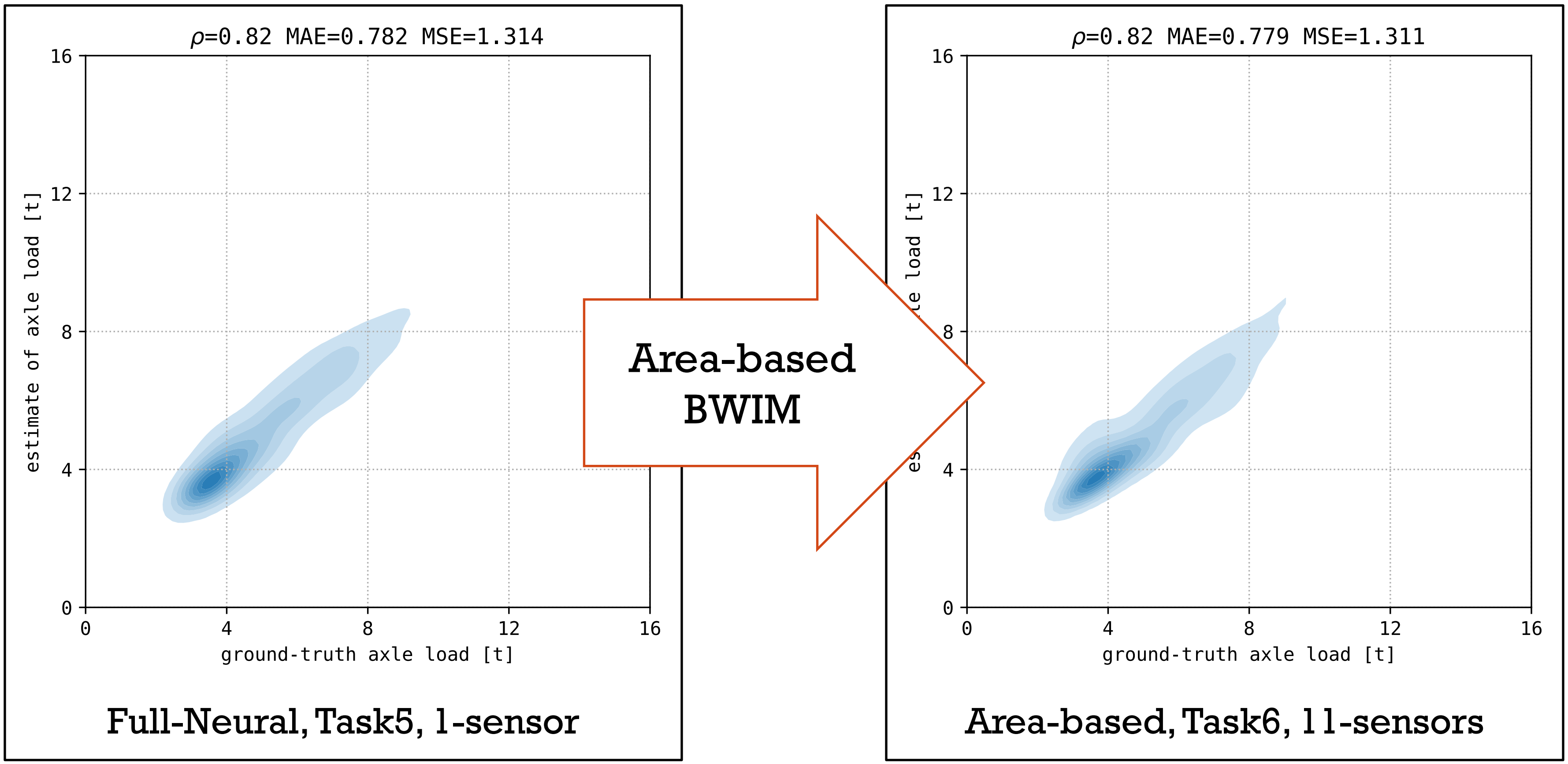
- Fully-neural BWIM used a single sensor installed beneath the deck.
- Area-based BWIM used all sensors at decks, girders, and v-stiffeners.

EXPERIMENTAL SETUP: AREA-BASED B-WIM

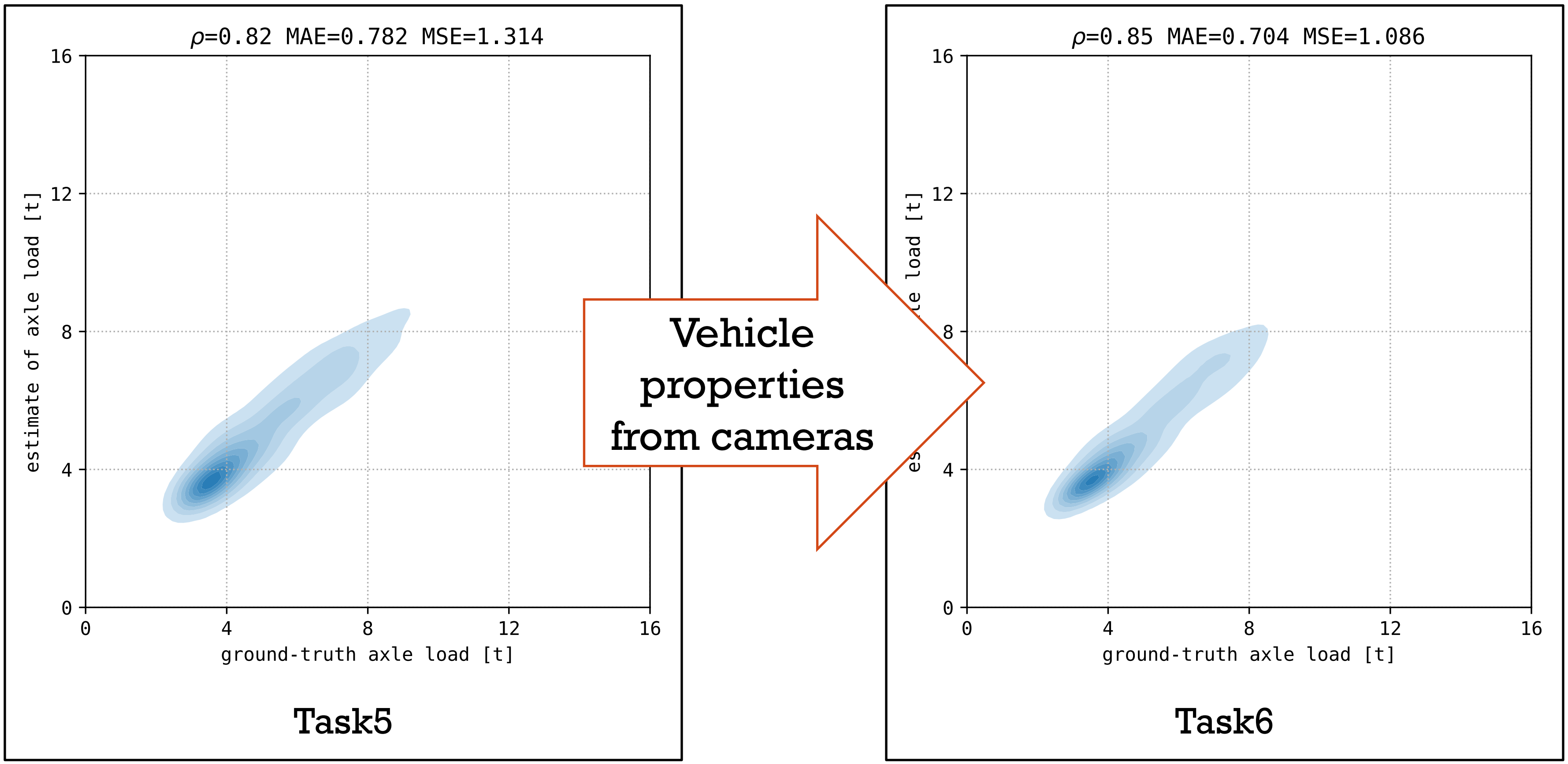
- Our special implementation estimated axle loads via 3 linear layers:



FULLY-NEURAL B-WIM VS AREA-BASED B-WIM



TASK5 VS CAMERA-ASSISTED TASK6



SUMMARY

Additional features from cameras

- were effective to improve axle-load accuracy.

vs Area-based BWIM

- equivalent although proposal utilized only a single sensor.

Future work

- combine the 11 sensors on decks, girders, and v-stiffeners.

THANK YOU!