FULLY-NEURAL APPROACH
TO VEHICLE WEIGHING AND STRAIN PREDICTION ON BRIDGES USING WIRELESS ACCELEROMETERS

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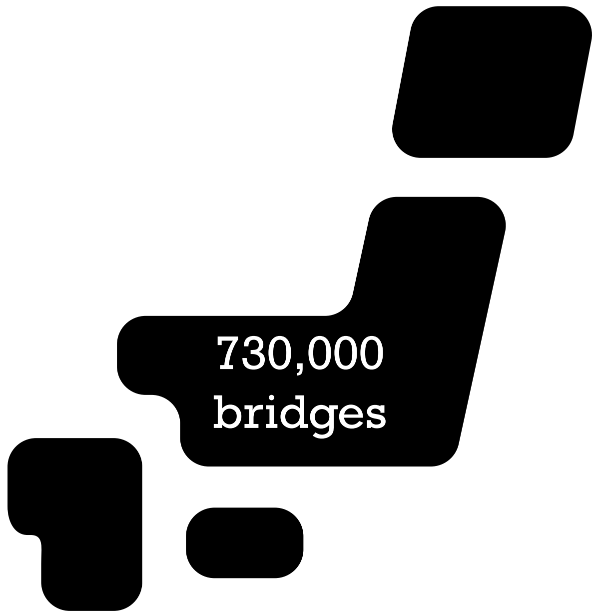
INTRODUCTION

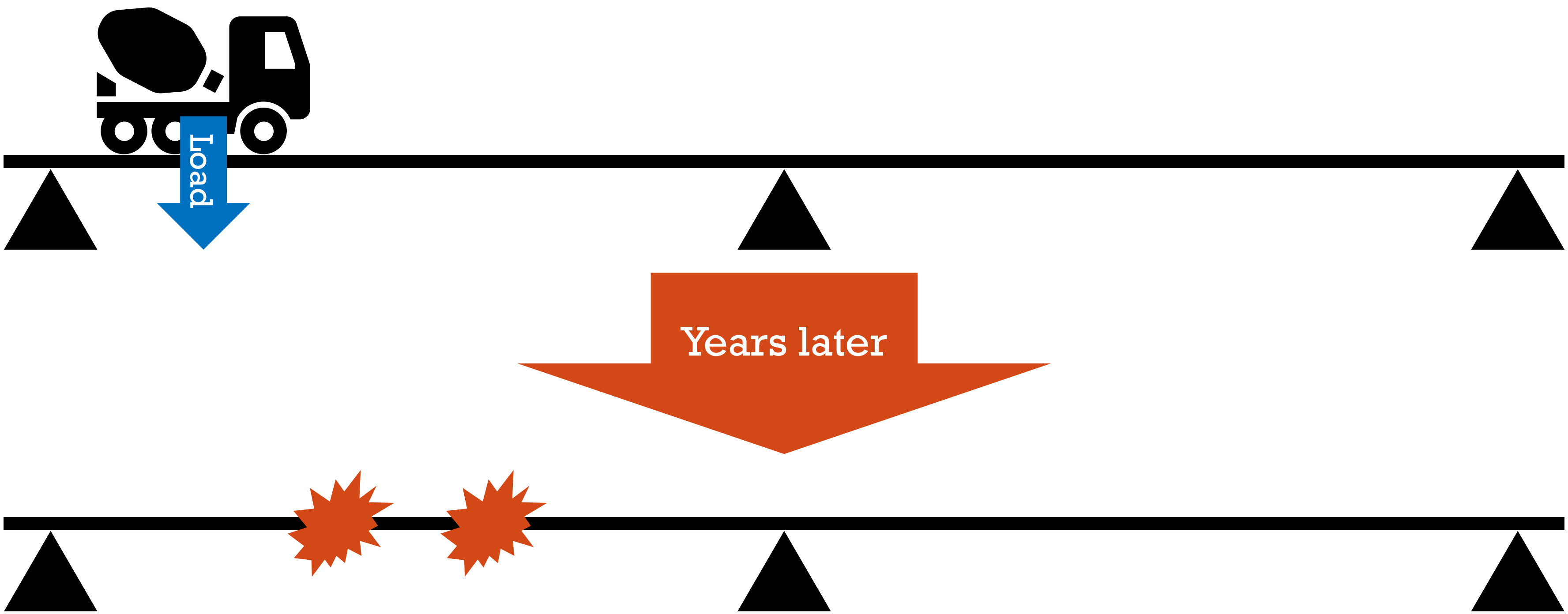
SERIOUS BRIDGE DETERIORATION PROBLEM

- Highly automated bridge health monitoring system is required!



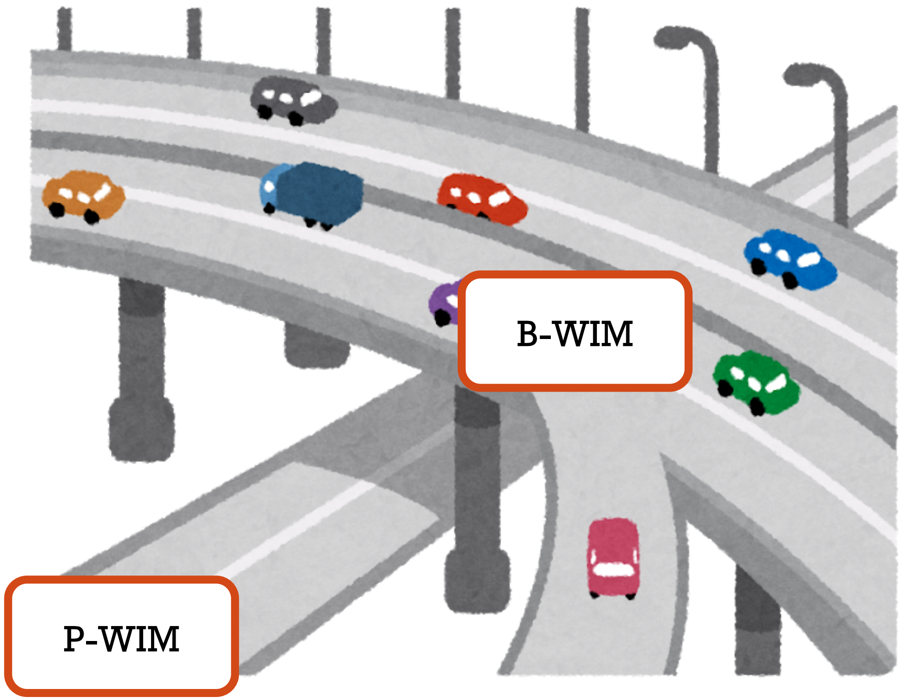
PROBLEM OF HEAVY VEHICLES

- Heavy vehicles may cause serious damage to bridge components:



WEIGH-IN-MOTION (WIM)

- WIM estimates axle loads of running vehicles without stopping them.
  - There are 2 major types, Pavement (P-) WIM and Bridge (B-) WIM:



P-WIMs

- Installed on road surface,
- Too expensive and fragile.

B-WIMs

- Utilize bridges as scales,
- Inexpensive and durable.

OUR GOAL IS

- to realize a simple but accurate BWIM system with 3 advantages:

Easy to install and maintain

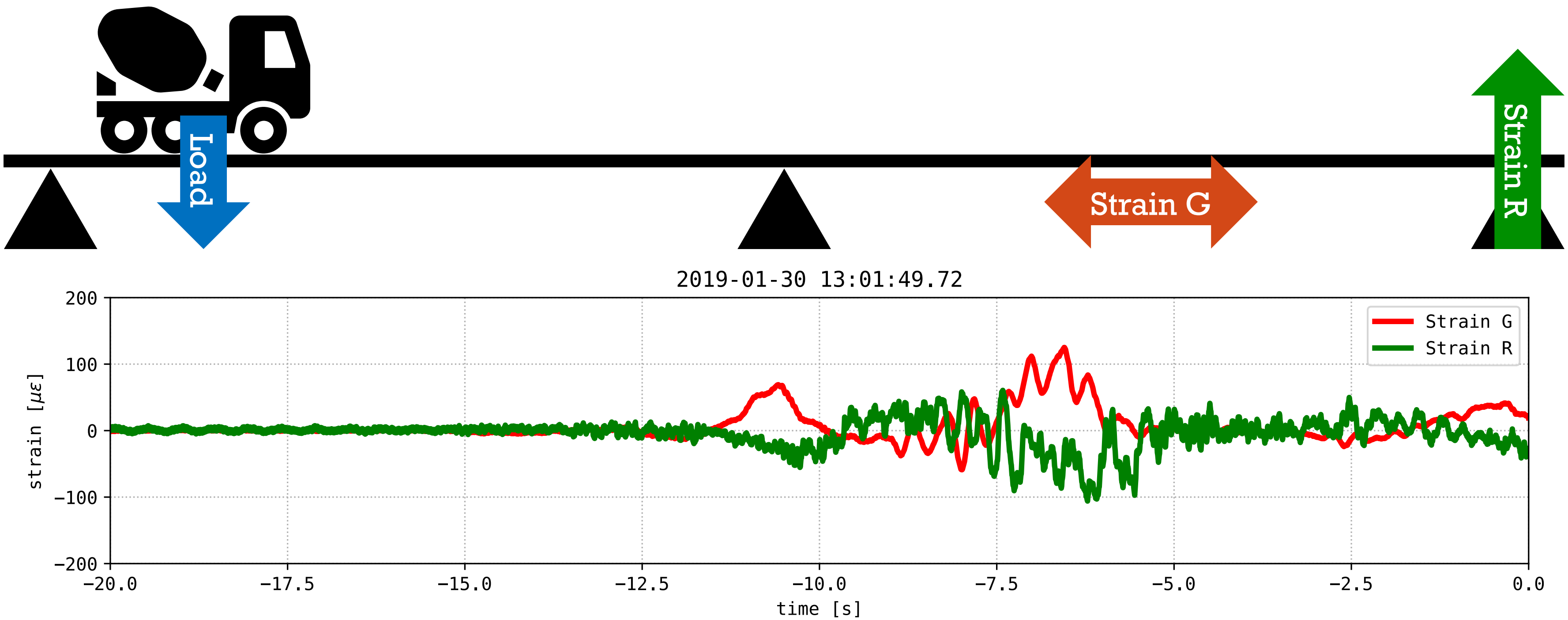
Obtains bridge models automatically

Robust in situations where vehicles run side by side

7 CONVENTIONAL B-WIM

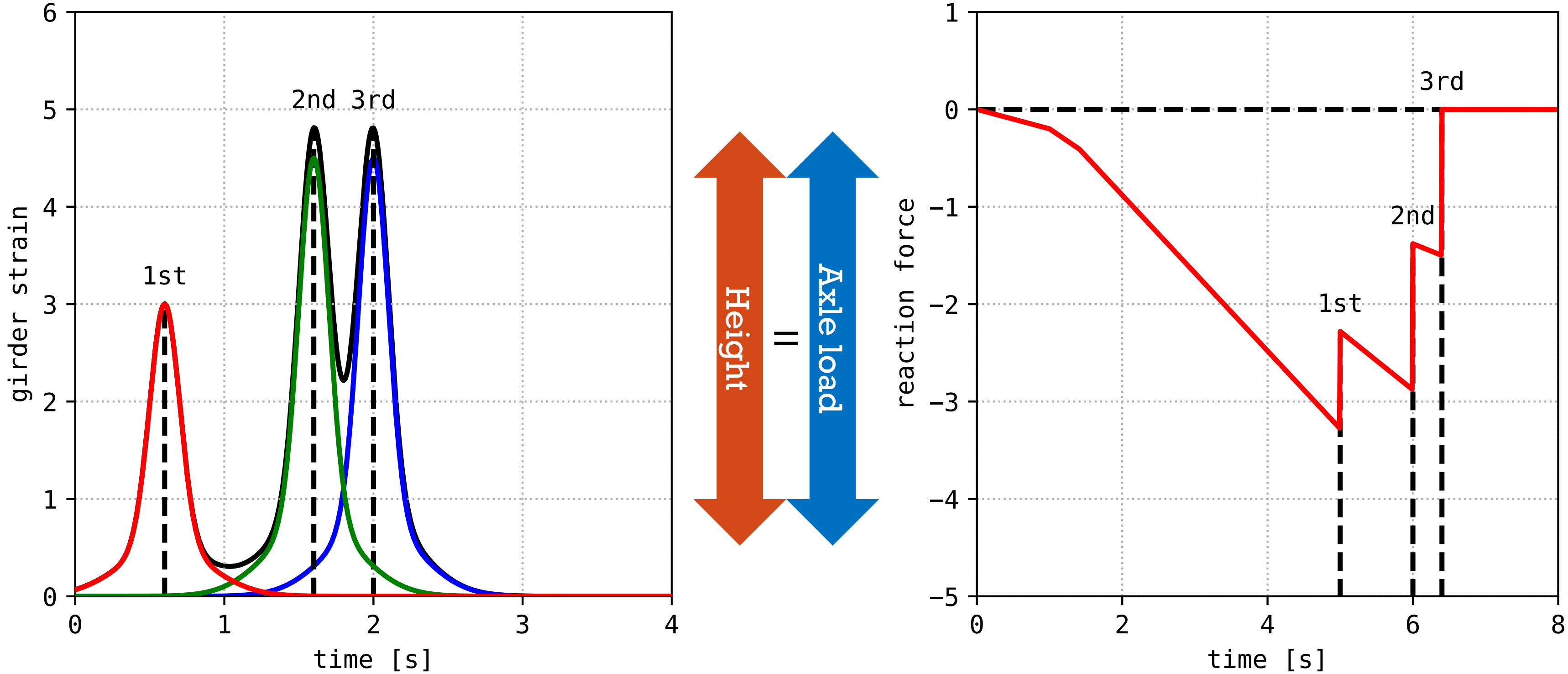
STRAIN-BASED B-WIM

- When a vehicle crosses a bridge, the bridge deforms in response:



AXLE-LOAD ESTIMATION

- By decomposing strain signal, individual axle loads can be obtained:



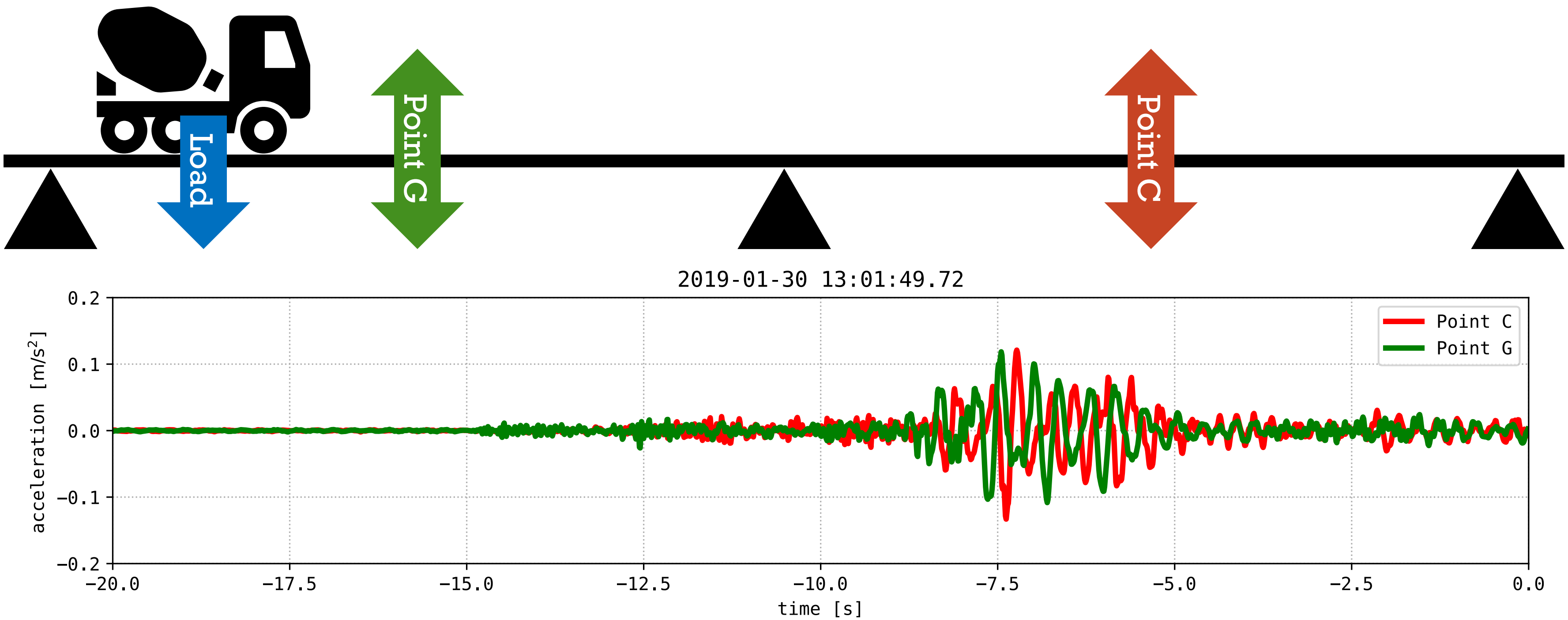
DIFFICULTY OF STRAIN MEASUREMENT

- B-WIM uses multiple strain sensors for accurate load estimation, but

Labor at a high place	Sensor failure	Power consumption
• Paint scratching • Careful attachment	• Frequent repair • Reconfiguration	• Resistive bridge • Wired strain gauges

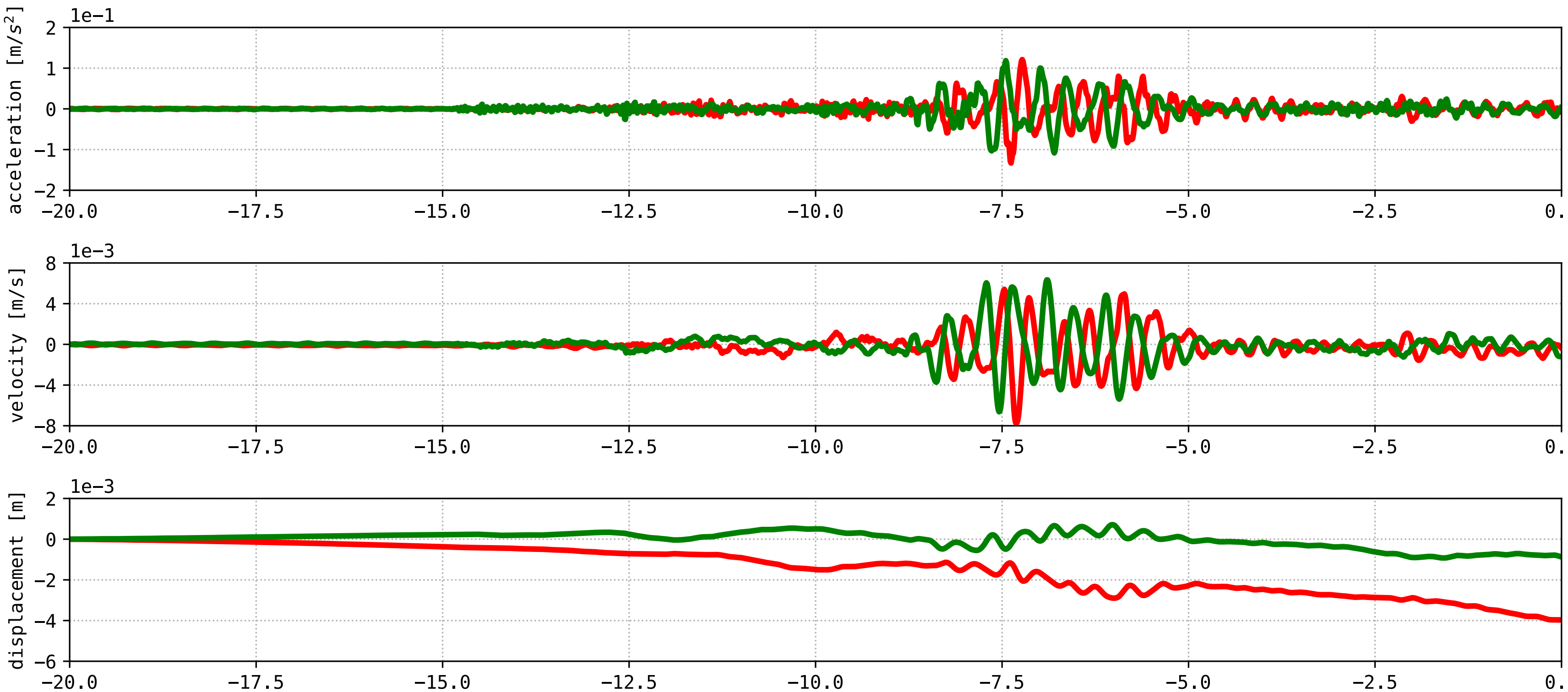
ACCELERATION-BASED B-WIM

- Use girder acceleration signal to obtain girder global displacement:



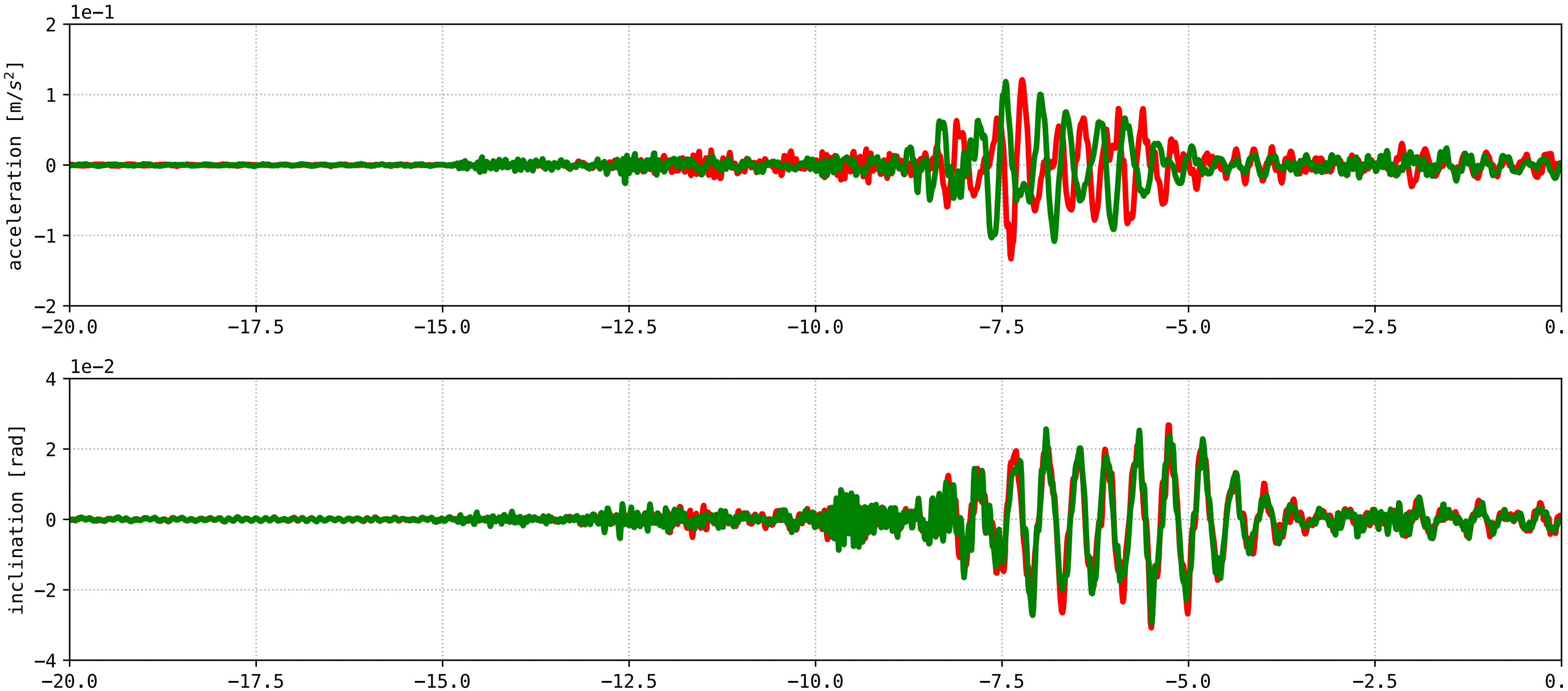
INTEGRATION APPROACH

- Due to noise, offset and bridge vibration, integration is not reliable:



INCLINATION APPROACH

- Use gravity component in acceleration signal to obtain inclination:



DIFFICULTY IN REAL PRACTICE

- These approaches require artisan skill for system (re-) initialization:

Installation	Bridge modeling	Vehicle detection
• Positioning • Calibration	• Kalman filter • Noise cancellation	• Lane • Speed • Trajectory • Axle positions • Vehicle separation

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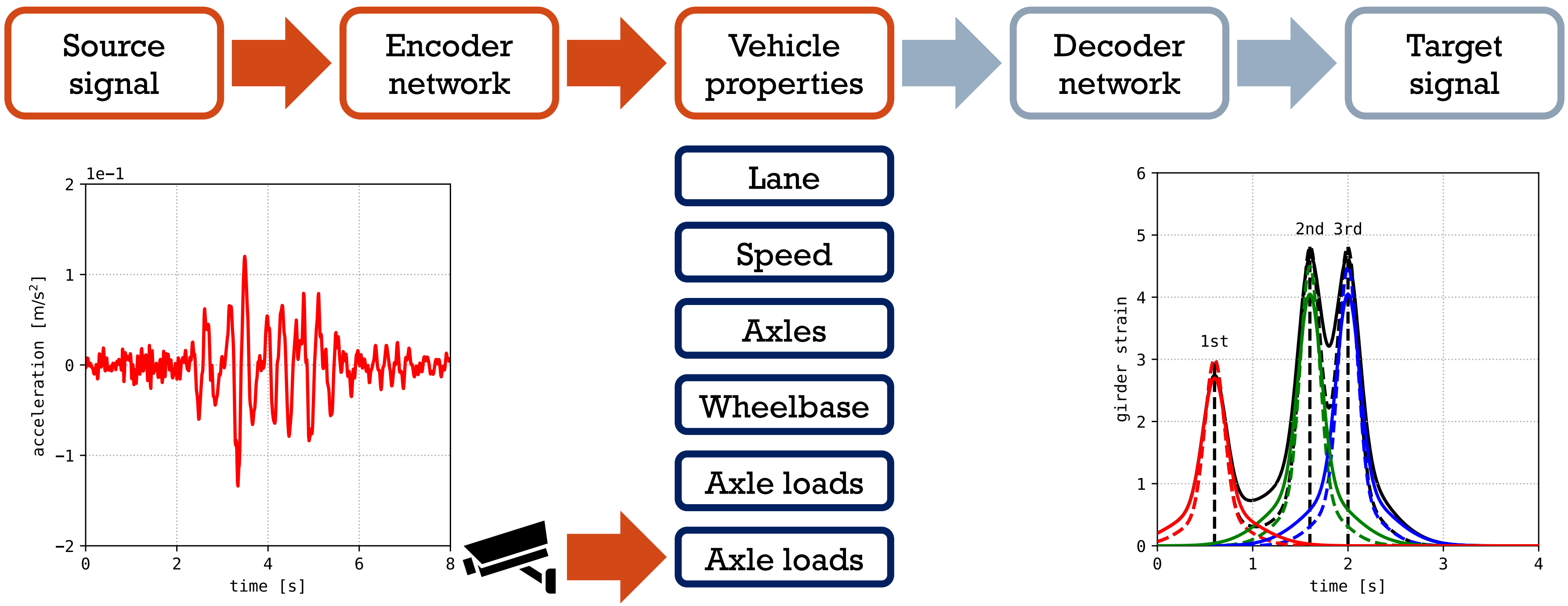
FULLY-NEURAL B-WIM

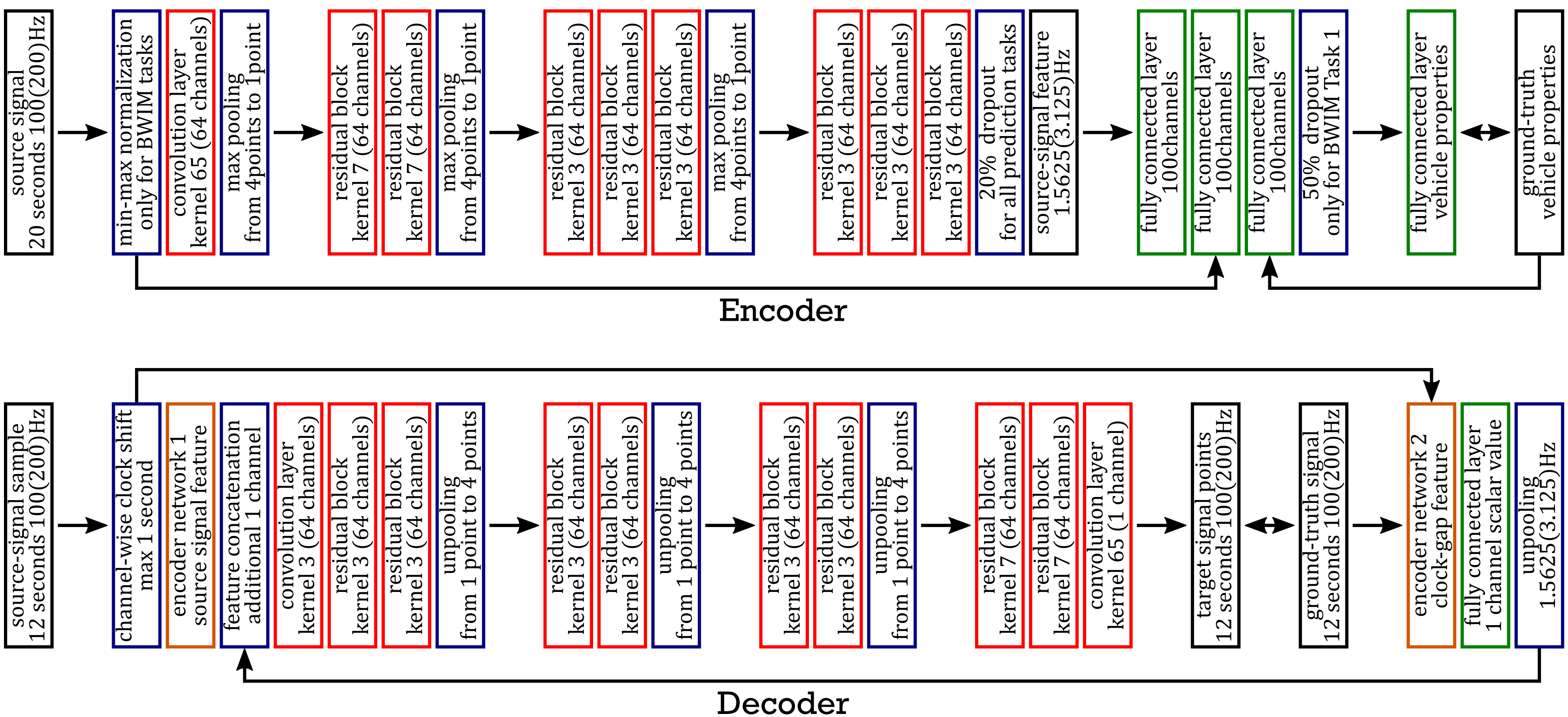
BRIDGE MODELING BY NEURAL NETWORK

- Vehicle properties may be estimated using a neural bridge model:



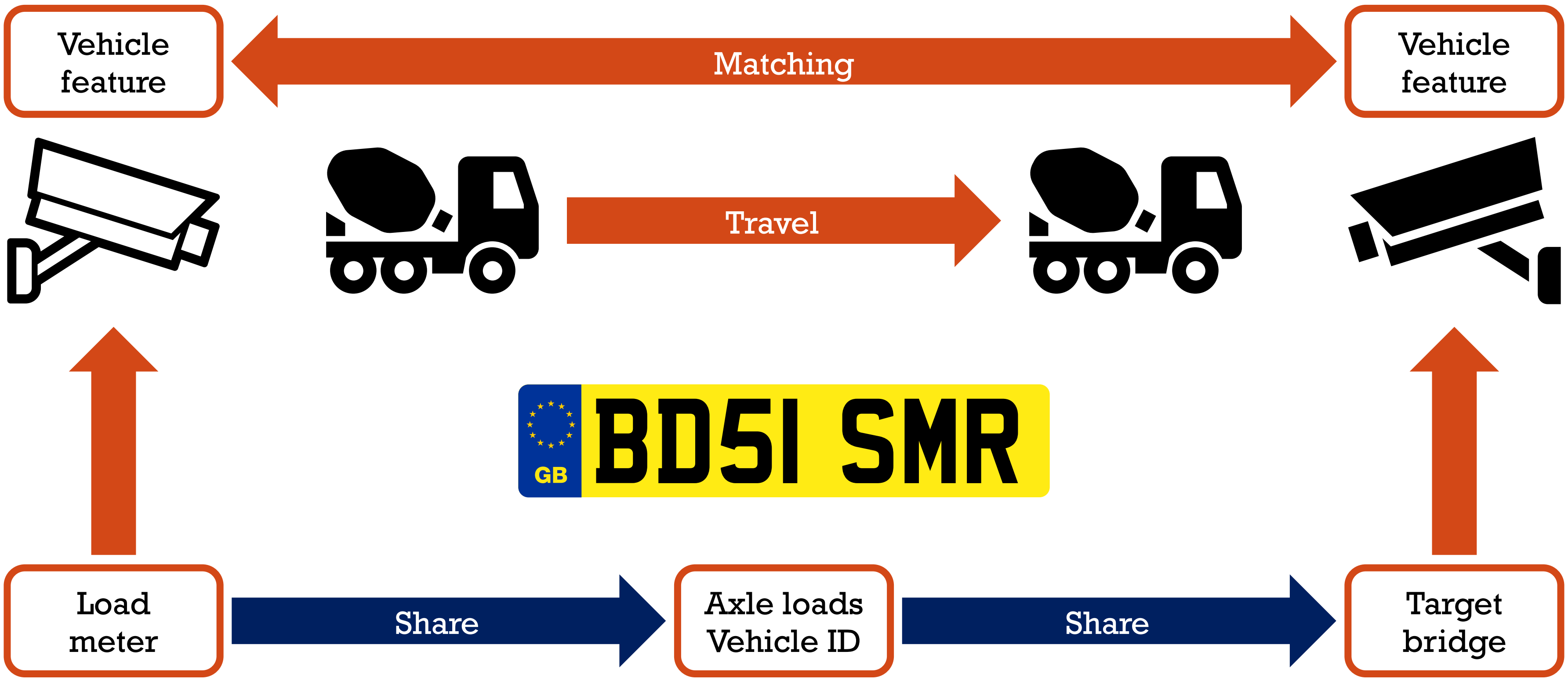
ENCODER-DECODER NETWORK ARCHITECTURE

- Encoder estimates axle loads and decoder estimates strain signals:



VEHICLE LINK SYSTEM (VLS)†

- Axle load information can be collected from WIM at distant location:



† Takaya Kawakatsu, Kenro Aihara, Atsuhiro Takasu, Jun Adachi
"Fully-Neural Approach to Heavy Vehicle Detection on Bridges Using a Single Strain Sensor"
ICASSP 2020

FULLY-NEURAL BRIDGE WEIGH-IN-MOTION†

- Use VLS to train many B-WIMs by ground truth from a few P-WIMs:

P-WIMs

- detect heavy vehicles,
- share vehicles & their IDs.

↓ 3.6km

B-WIMs

- learn known vehicles,
- weigh unknown vehicles.

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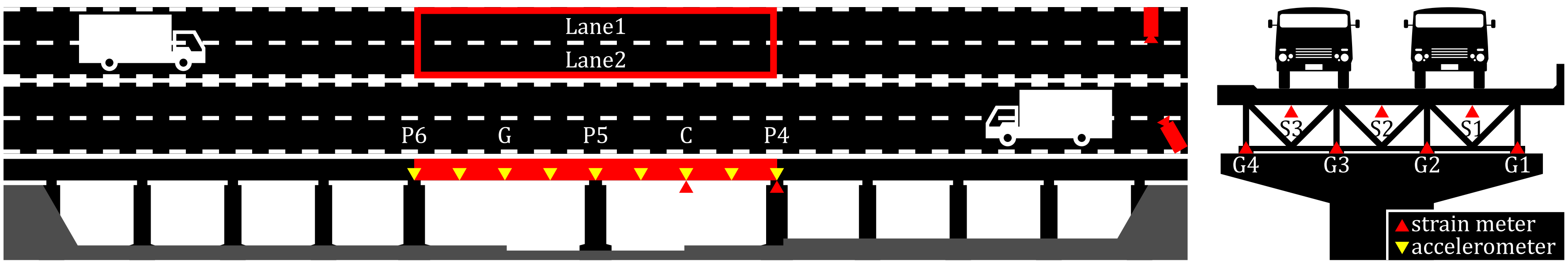
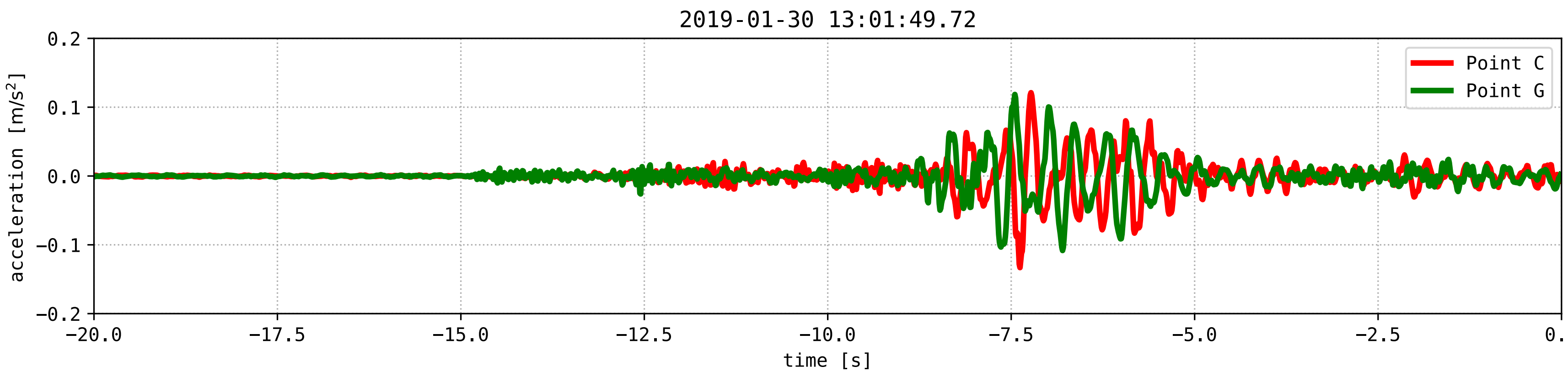
Experimental Results

TARGET BRIDGE AND ACCELERATION SIGNALS

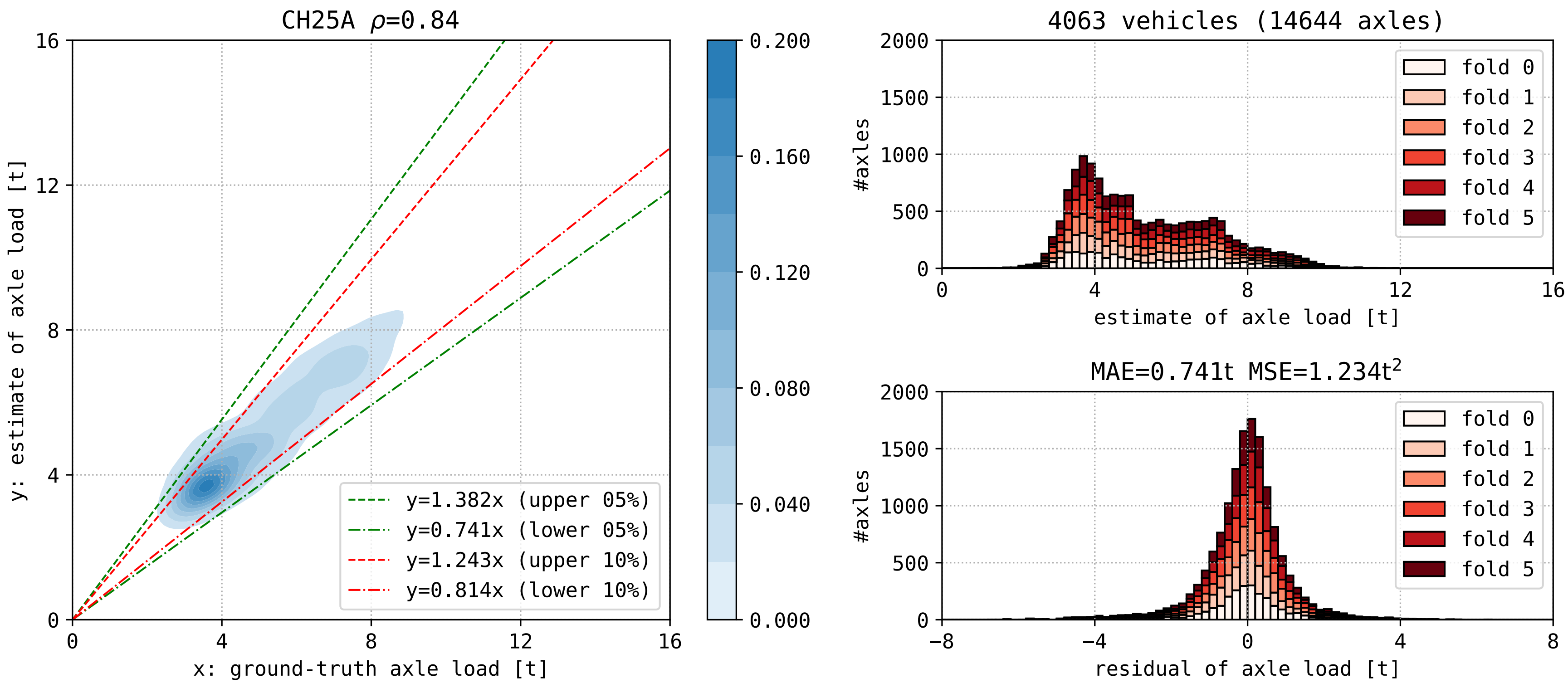
- We installed 9 accelerometers on girder G2 on expressway bridge:





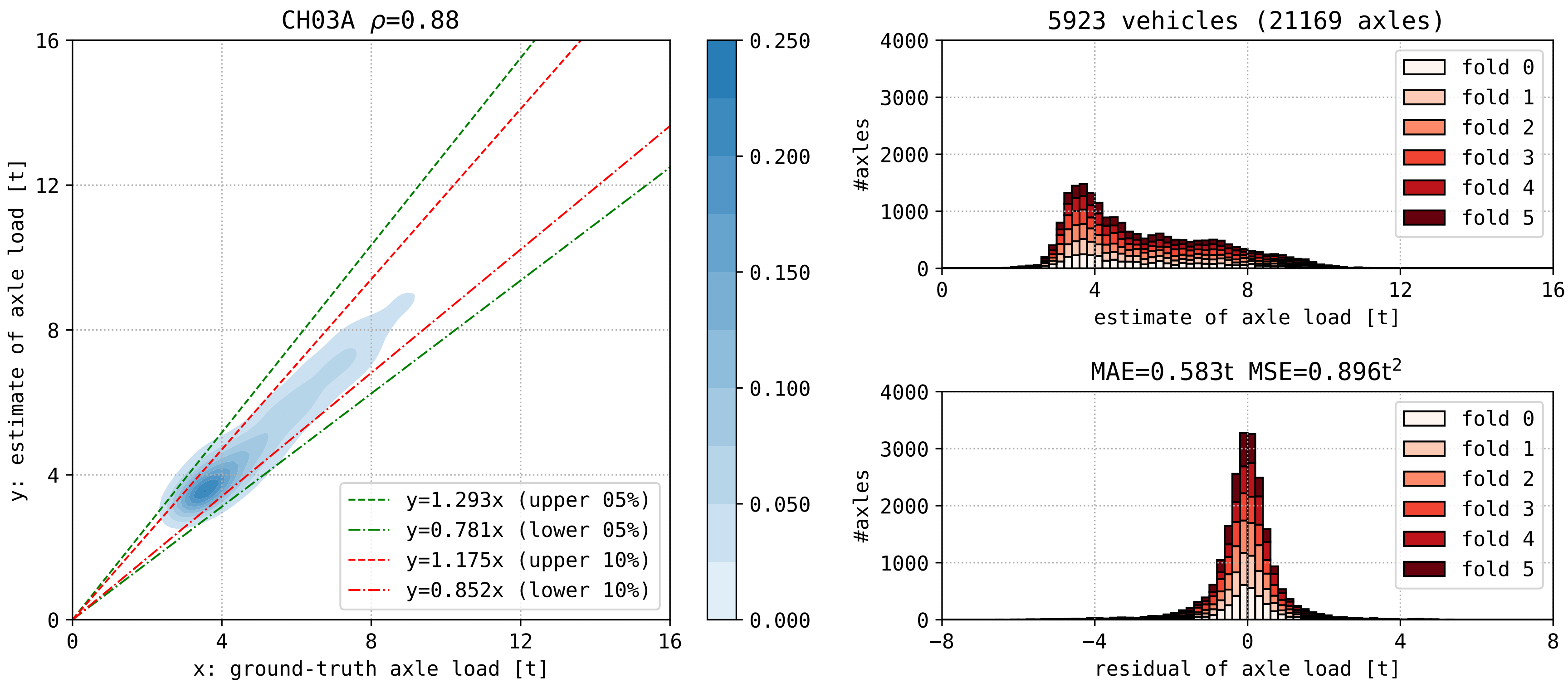
LOAD ESTIMATION USING ACCELEROMETERS

- CNN successfully predicted 14,644 axle loads from 4,063 vehicles:



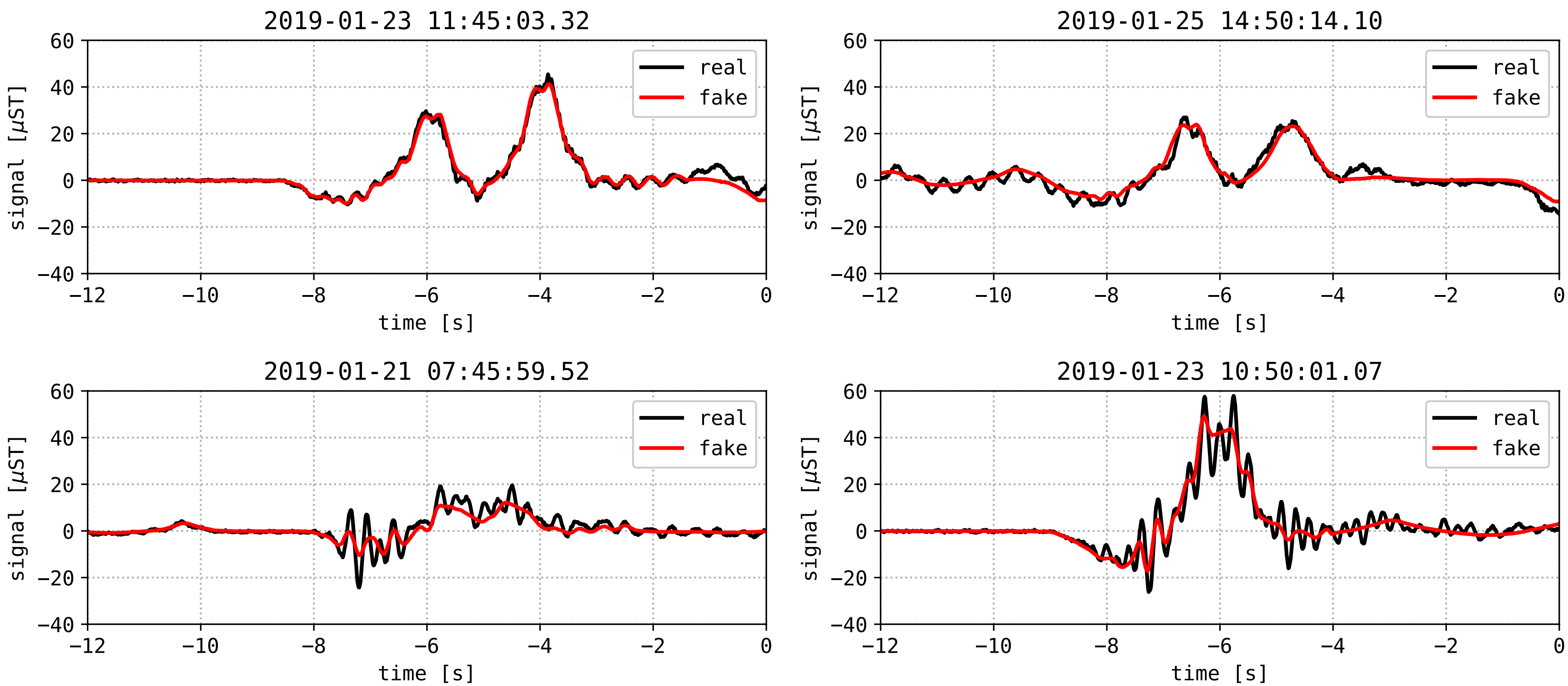
LOAD ESTIMATION USING STRAIN SENSOR

- CNN using strain sensors achieved better accuracy than proposal:



STRAIN ESTIMATION USING ACCELEROMETERS

- Good performance in situations where 2 vehicles ran side by side:



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CONCLUSION

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- CNN simulates girder dynamics using real noisy acceleration data.
- CNN learns real traffic situations using cameras and distant P-WIM.
- Experimental results demonstrate the detectability of axle weights.
- This should lead to low-cost WIM that is easy to install and maintain.

OUR PREVIOUS WORK

Deep Sensing Approach to Single-Sensor Vehicle Weighing System on Bridges

- IEEE Sensors Journal, Volume 19, Issue 1, 2019.

Fully-Neural Approach to Heavy Vehicle Detection on Bridges Using a Single Strain Sensor

- 45th IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), 2020.

Deep Learning Approach to Modeling Bridge Dynamics Using Cameras and Sensors

- 10th International Conference on Bridge Maintenance, Safety and Management (IABMAS), 2020.

Adversarial Media-Fusion Approach to Strain Prediction for Bridges

- 8th International Conference on Pattern Recognition Applications and Methods (ICPRAM), 2019.

Adversarial Spiral Learning Approach to Strain Analysis for Bridge Damage Detection

- 20th International Conference on Big Data Analytics and Knowledge Discovery (DaWaK), 2018.

Deep Sensing Approach to Single-Sensor Bridge Weighing in Motion

- 9th European Workshop on Structural Health Monitoring (EWSHM), 2018.

Traffic Surveillance System for Bridge Vibration Analysis

- 4th International Workshop on Information Integration in Cyber Physical Systems (IICPS), 2017.

THANK YOU!