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!

730,000 bridges
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
CONVENTIONAL B-WIM
STRAIN-BASED B-WIM

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

<table>
<thead>
<tr>
<th>Labor at a high place</th>
<th>Sensor failure</th>
<th>Power consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Paint scratching</td>
<td>• Frequent repair</td>
<td>• Resistive bridge</td>
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<td>• Careful attachment</td>
<td>• Reconfiguration</td>
<td>• Wired strain gauges</td>
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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:

![Graph showing acceleration and inclination over time.](image-url)
DIFFICULTY IN REAL PRACTICE

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

<table>
<thead>
<tr>
<th>Installation</th>
<th>Bridge modeling</th>
<th>Vehicle detection</th>
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</thead>
<tbody>
<tr>
<td>Positioning</td>
<td>Kalman filter</td>
<td>Lane</td>
</tr>
<tr>
<td>Calibration</td>
<td>Noise cancellation</td>
<td>Speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trajectory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Axle positions</td>
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<td>Vehicle separation</td>
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FULLY-NEURAL B-WIM
Vehicle properties may be estimated using a neural bridge model:
Encoder-Decoder Network Architecture

- Encoder estimates axle loads and decoder estimates strain signals:

![Diagram of Encoder-Decoder Network Architecture](image-url)
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\textsuperscript{†}

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

**P-WIMs**
- detect heavy vehicles,
- share vehicles & their IDs.

**B-WIMs**
- learn known vehicles,
- weigh unknown vehicles.

\textsuperscript{†}Takaya Kawakatsu, Kenro Aihara, Atsuhiro Takasu, Jun Adachi
“Fully-Neural Approach to Heavy Vehicle Detection on Bridges Using a Single Strain Sensor”
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EXPERIMENTAL RESULTS
TARGET BRIDGE AND ACCELERATION SIGNALS

- We installed 9 accelerometers on girder G2 on expressway bridge:
CNN successfully predicted 14,644 axle loads from 4,063 vehicles:
CNN using strain sensors achieved better accuracy than proposal:
Good performance in situations where 2 vehicles ran side by side:
CONCLUSION
CONCLUSION

- 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

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

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
THANK YOU!