The behavior analysis of
Spatial Singular Mode Angle
due to addition of noise to the data in **an actual bridge experiment**

the 10th EWSHM in Parelmo

2022, July 4.

Yuta Takahashi

Yachiyo engineering, Japan.

Naoki Kaneko, Ryota Shin, **Kyosuke Yamamoto**(Presenter)

University of Tsukuba, Japan.

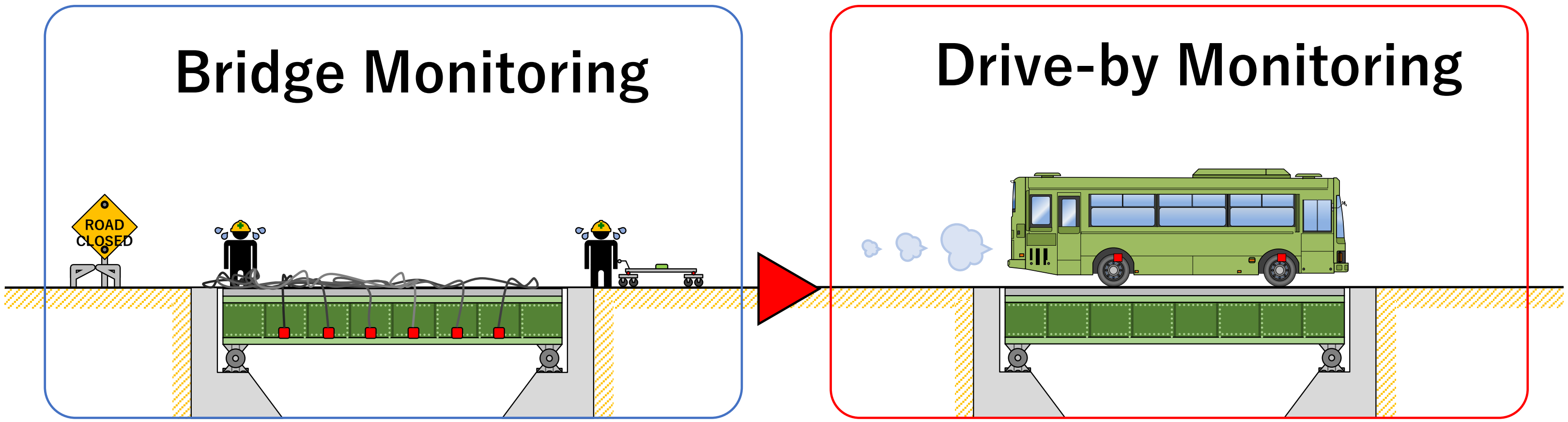
Our Theme

Practical and Robust **Drive-by Monitoring**

- Cyber Physics System (CPS) realizes the data-driven management.
  - The construction needs BIG data for infrastructure, bridge, road surface etc…
  - This study focuses on the bridge.
- The measurement should be practical.
  - The COST is required as being low (about energy supply, data communication, the sensor installation)
  - Drive-by monitoring can reduce the cost of the sensor installation.

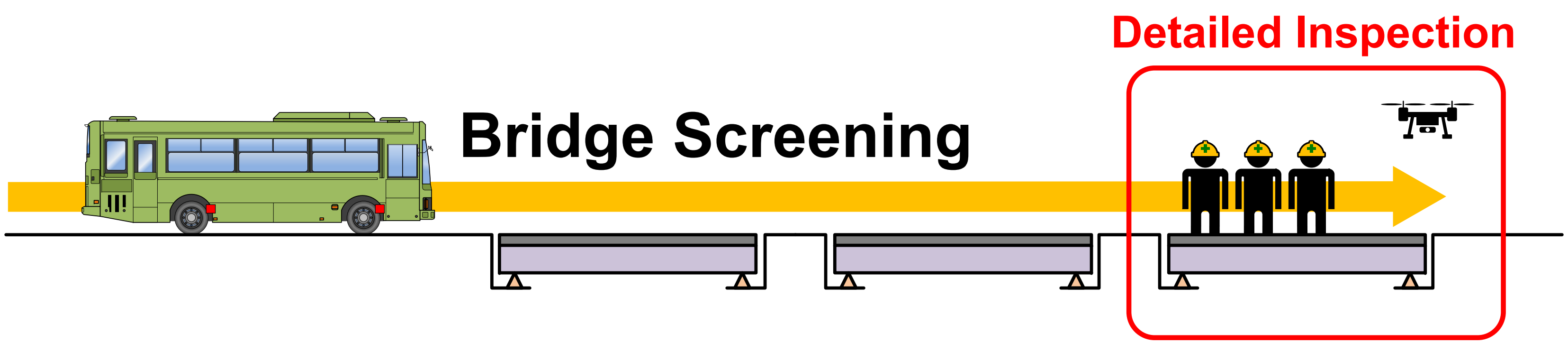
Data driven SHM for bridge

- The measurement by **sensors on bridge** may be labor-consuming.
- The **sensors on vehicle** can collect a lot of data from many bridges only by running.
  - Their popular damage indices are natural frequency (NF) and mode shape (MS).
  - NF are often affected by noise, and it is necessary to use expensive sensor for detection of damage.
  - MS is more sensitive, however, it requires precise allocation.



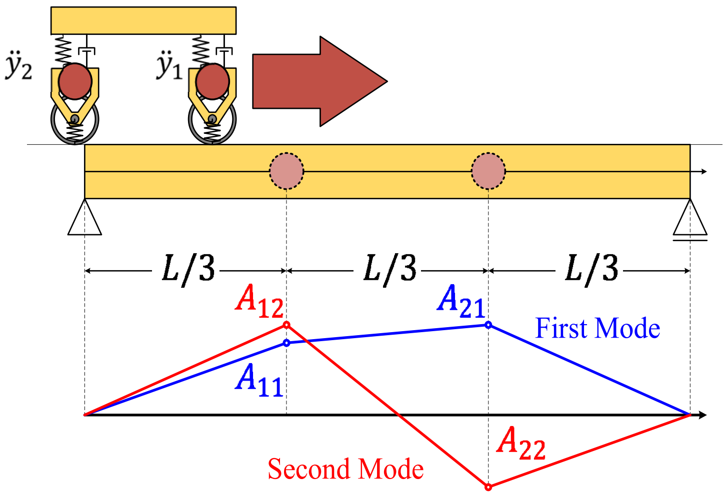
Application of Drive-by Monitoring

- Collect big data by **vehicles with vibration sensors and GPS**
- Extract bridge vibration components from the vehicle vibration data
- Evaluate the bridge condition based on the estimated bridge vibration
- Inspect only "**damage-suspected**" bridges



Drive-by Technology for Screening: **SSMA**

- **<u>S</u>**<u>patial</u> **<u>S</u>**<u>ingular</u> **<u>M</u>**<u>ode</u> **<u>A</u>**<u>ngle</u> is Estimated Bridge Mode Shape



Measure the **un-sprung vehicle vibrations**

$$\ddot{\boldsymbol{y}}(t) = \begin{Bmatrix} \ddot{y}_1(t) \\ \ddot{y}_2(t) \end{Bmatrix}$$

Estimate the bridge vibration

$$\mathbf{N}^{-1}(\boldsymbol{x}) \times \ddot{\boldsymbol{y}}(t) = \mathbf{U} \times \boldsymbol{\Sigma} \times \boldsymbol{V}^{\mathrm{T}}$$

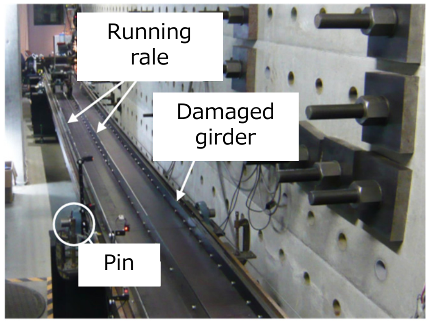
SVD

Interpolation:
(Conversion from the **travelling points** to the **point fixed on bridge**)

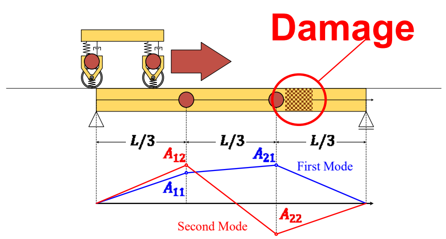
$$SSMA = \tan^{-1}\left(\frac{A_{21}}{A_{11}}\right) = \tan^{-1}\left(-\frac{A_{12}}{A_{22}}\right)$$

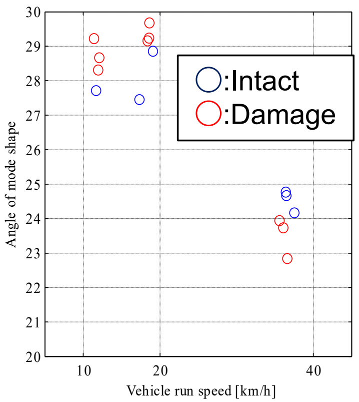
Previous Study

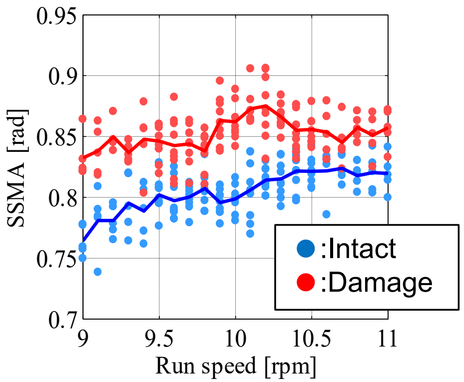
- **SSMA** is relatively **robust** and **sensitive**.
  (not affected by noise) (changes well for structural changes)

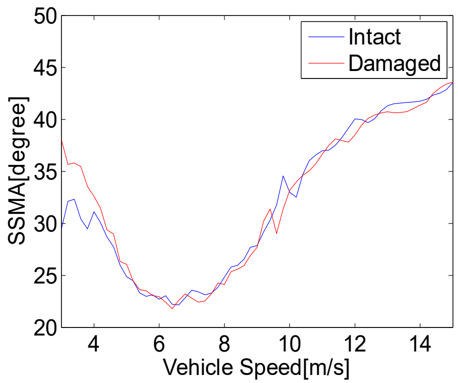


Numerical Model



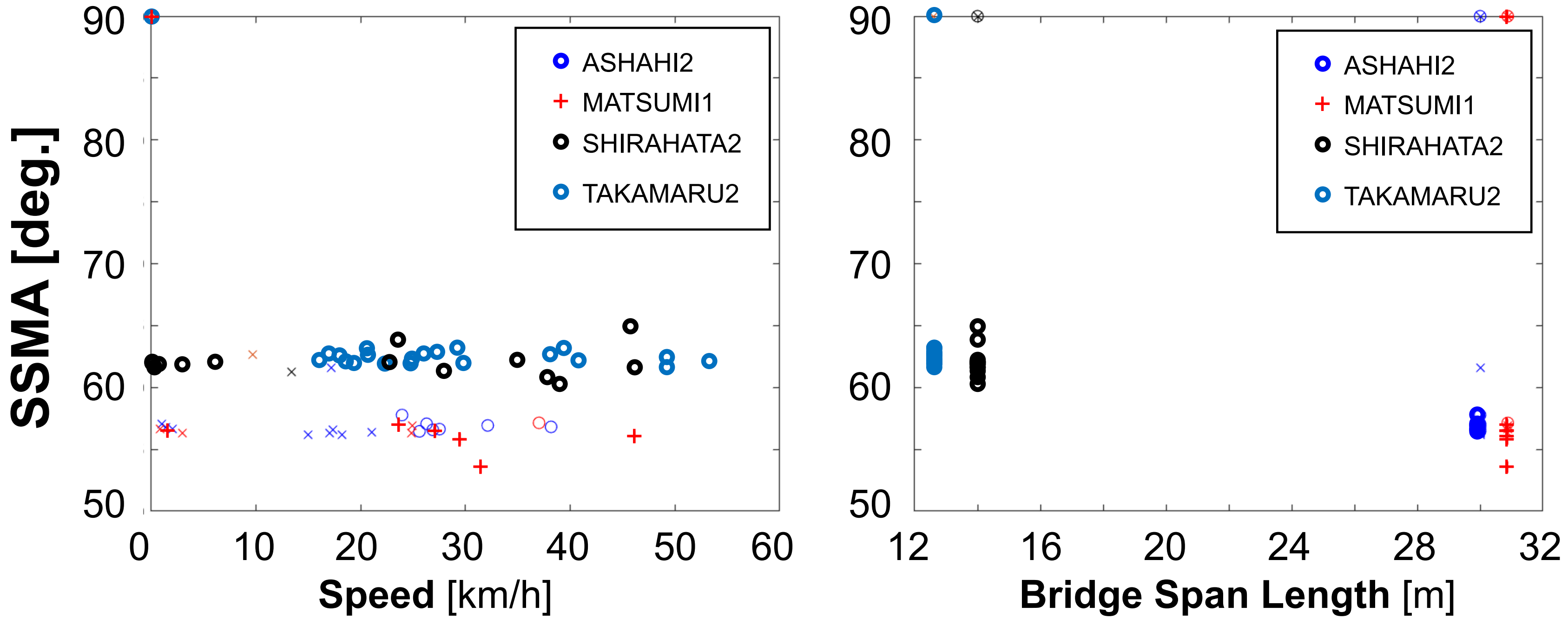






Tendency of SSMA and Bridge Span

- **SSMA** tends to depend on **bridge length**



* Y.Takahashi et al, EVACES2021

The **Purpose** of this Study

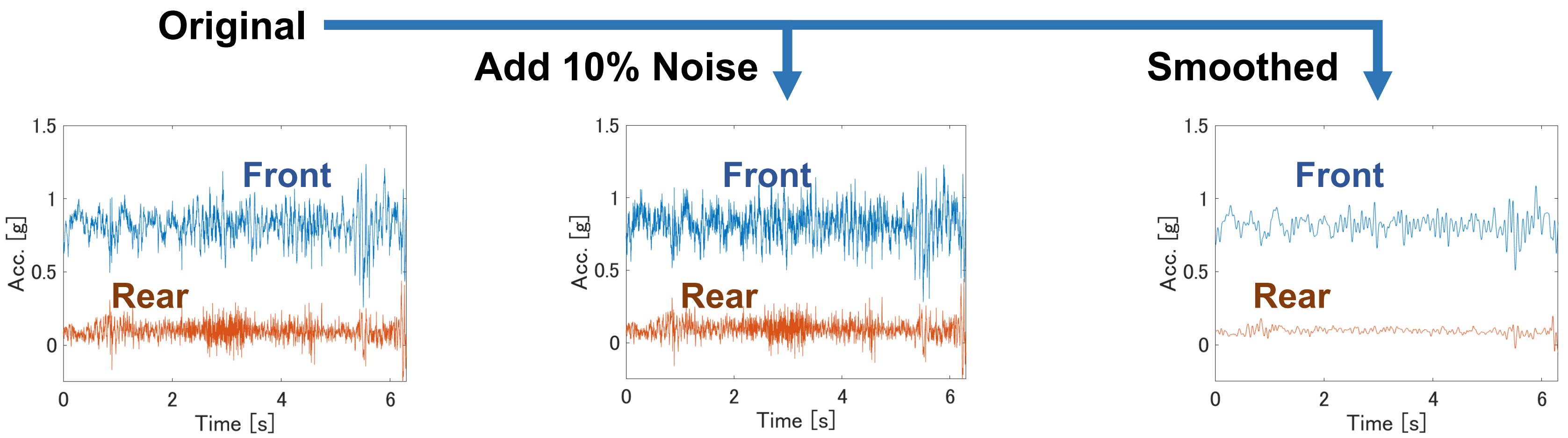
- To try to decrease the **variance of SSMA** by two schemes

  1. **Noise Adding**

  2. **Smoothing**

Method: Noise and Smoothing

- **Noise Adding**
  - Original signals are amplified by Noise (ratio: ±5~10%)
  - Notice that the additional noise is white noise.
- **Smoothing**
  - The **smoothed signal** are produced by Gaussian Filter from the original. (**Low-Pass Filter**)
  - Window size is changed to **4** (~75Hz), **20** (~15Hz), and **40** (~7.5Hz).

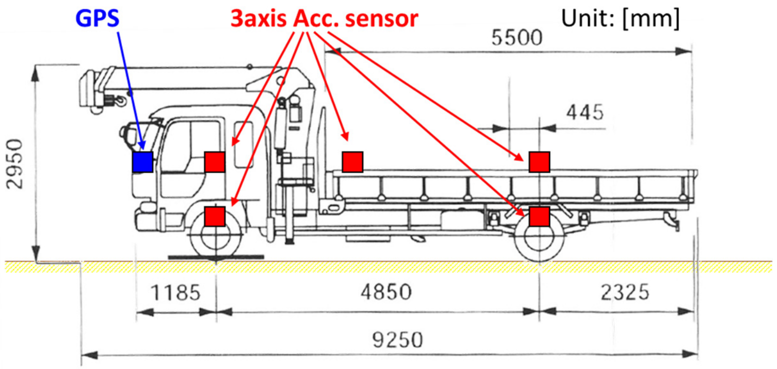


Experiment

- The field experiment is carried out for **4** bridges

Bridge (name)	Type	Span [m]	Run [times]
PC1(TAKAMRU)	PC	12.6	26
PC2(SHIRAHATA)	PC	14	26
PC3(MATSUMI)	PC	30.88	25
S1(ASAHI)	Steel	30	24

13.8t



PC1

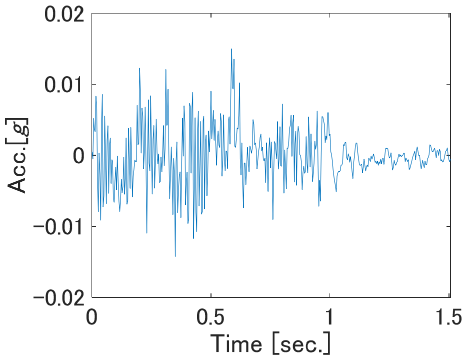
PC2

S1

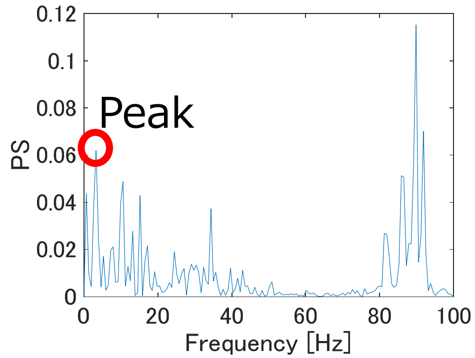
Experiment Movie : PC3

Example of Measured Data

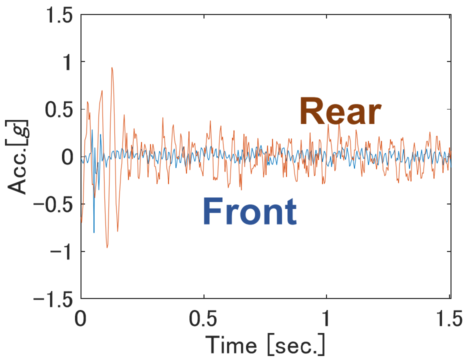
Mid-span of the Bridge

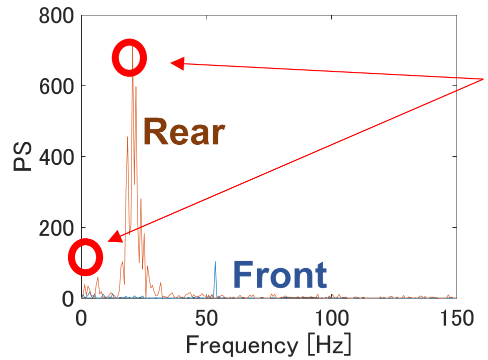


Electrical noise ?



Unsprung of the Vehicle





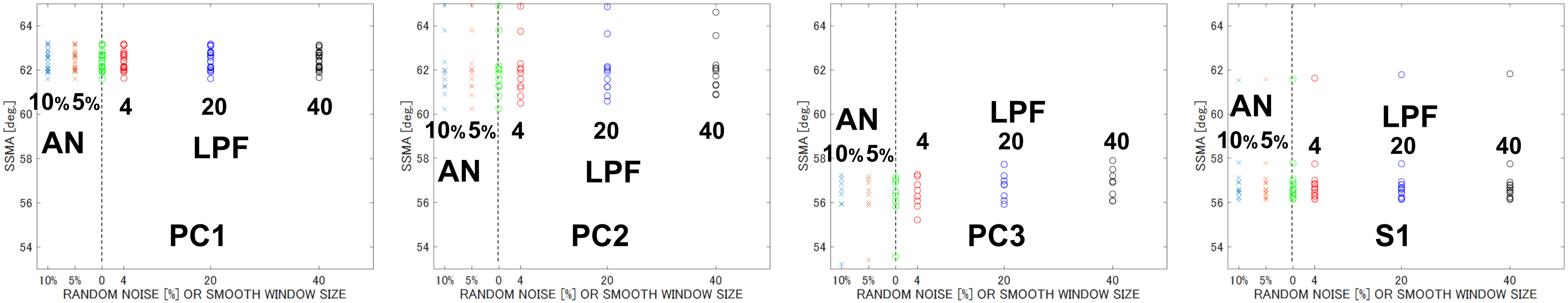
Natural Frequencies of the vehicle?

Acceleration **FFT**

Result

- **Noise Adding**: a little difference of SSMA from original.
  - 10% random noise is high on previous studies**.
  - Only S1 tends to be converged in spite of increasing noise ratio.
- **Smoothing**: the variance decreases better in longer PC bridge.
  - Bridge length: PC1<PC2<(S1)<PC3.
  - Over 20 window size, the variance decrease is not clear, comparing with window size 4 on PC3.
  - Smoothing increases the variance of S1.

** For example,
Eugene J Obrien, 2017.



Discussion

Variance change of SSMA

	Noise-Adding		Window Size			
Bridge	**10%**	**5%**	**0**	**4**	**20**	**40**
PC1	0.231	0.214	**0.200**	0.194	0.197	**0.180**
PC2	1.764	1.752	**1.739**	1.648	1.562	**1.273**
PC3	1.627	1.467	**1.321**	0.485	**0.362**	0.437
S1	**2.043**	2.058	**2.076**	2.100	2.217	2.249

- In **PC** Bridges, **Smoothing** can decrease the SSMA variance:
  - PC bridge is more “rigid”,
- In a **Steel** Bridge, **Noise-Adding** can decrease the SSMA variance:
  - Noise can disturb the influence from unknown factors, while smoothing deletes the structural information

Conclusion & Future Works

- **Conclusion**
  - **Noise-Adding** and **Smoothing** can decrease the **SSMA variances**
    - On PC bridges, Smoothing can work well, while Noise-Adding doesn't.
    - On the steel bridge, Noise-Adding can work well, while Smoothing doesn't.
  - The difference of **bridge type** should be considered for variance-reduction.

- **Future Works**
  - Field Exp. on 121 bridges has been done:
  - We will analyze SSMA distributions from **Length**, **Type** and **Damage.**

筑波大学
University of Tsukuba

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Acknowledge & Reference

Acknowledge:

This study use sensors developed by **Mr. Ono** who is engineer stuff in university of Tsukuba.

We appreciate his great works.

IN SLIDES:

* Yuta Takahashi et al, The validation of sensor on-vehicle for evaluation of actual bridges with signal processing,9th International Conference on Experimental Vibration Analysis for Civil Engineering Structures (EVACES2021)

**Eugene J Obrien et al, Application of empirical mode decomposition to drive-by bridge damage detection, European Journal of Mechanics-A/Solids, 2017.

- Y B Yang et al, Extracting bridge frequencies from the dynamic response of a passing vehicle, Journal of Sound and Vibration, 2004.
- T. Nagayama et al, Bridge natural frequency estimation by extracting the common vibration component from the responses of two vehicles. Engineering Structures, 2017.
- K. Yamamoto and M. Ishikawa, Numerical Verification of Bridge Screening Technology based on Vehicle Vibration. Lecture Notes in Engineering and Computer Science: Proceedings of The World Con-gress on Engineering 2016, 2016.