MATLAB EXPO

클라우드 기반 교량의 장기 성능 평가 시스템 개발

박종웅 교수, 중앙대학교

MathWorks

목차

회사 및 발표자 약력

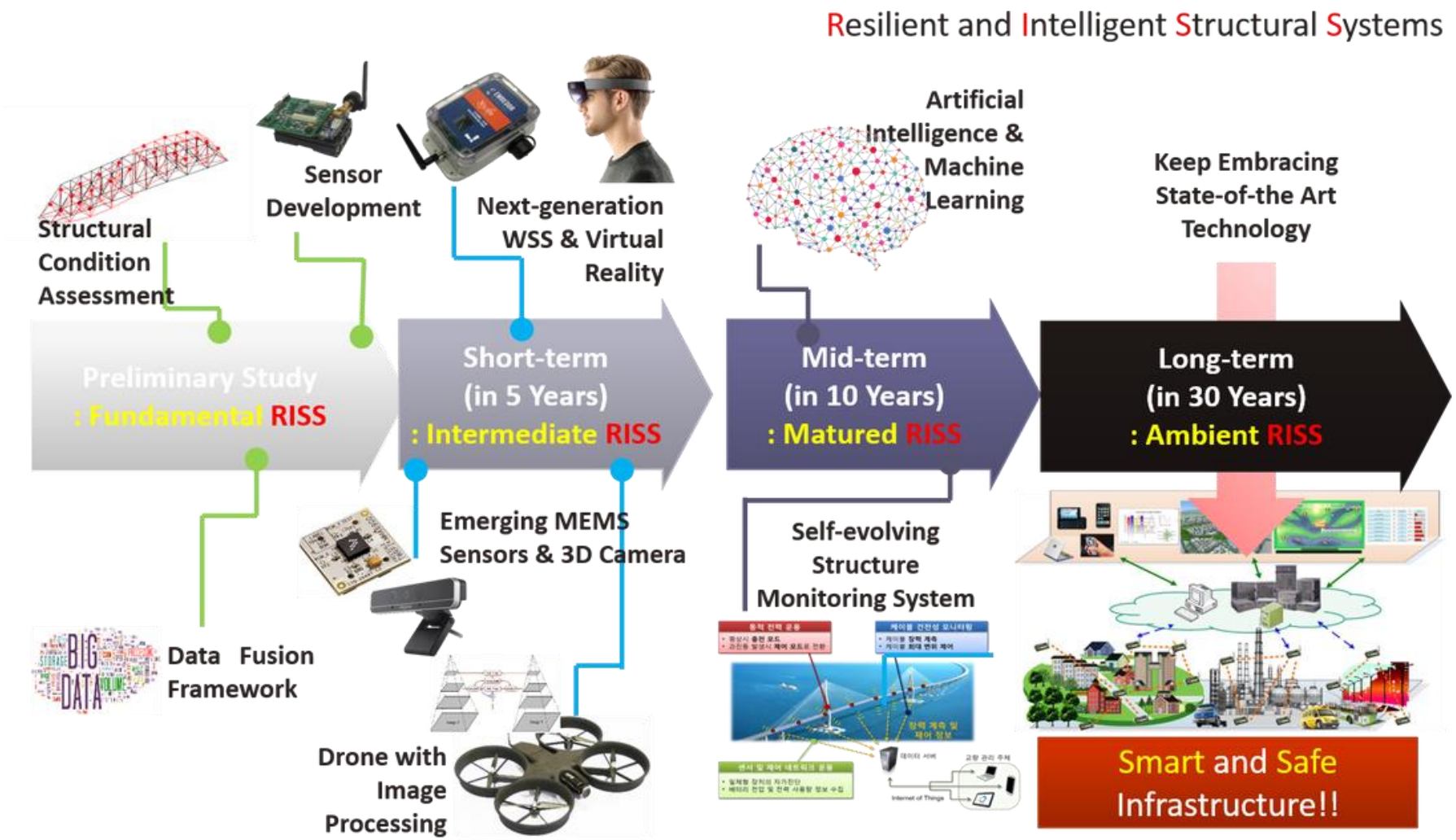
학력

- KAIST 건설환경공학 공학박사 (2013)
- KAIST 건설환경공학, 석사(2009)
- 한양대학교 토목공학과 학사 (2008)

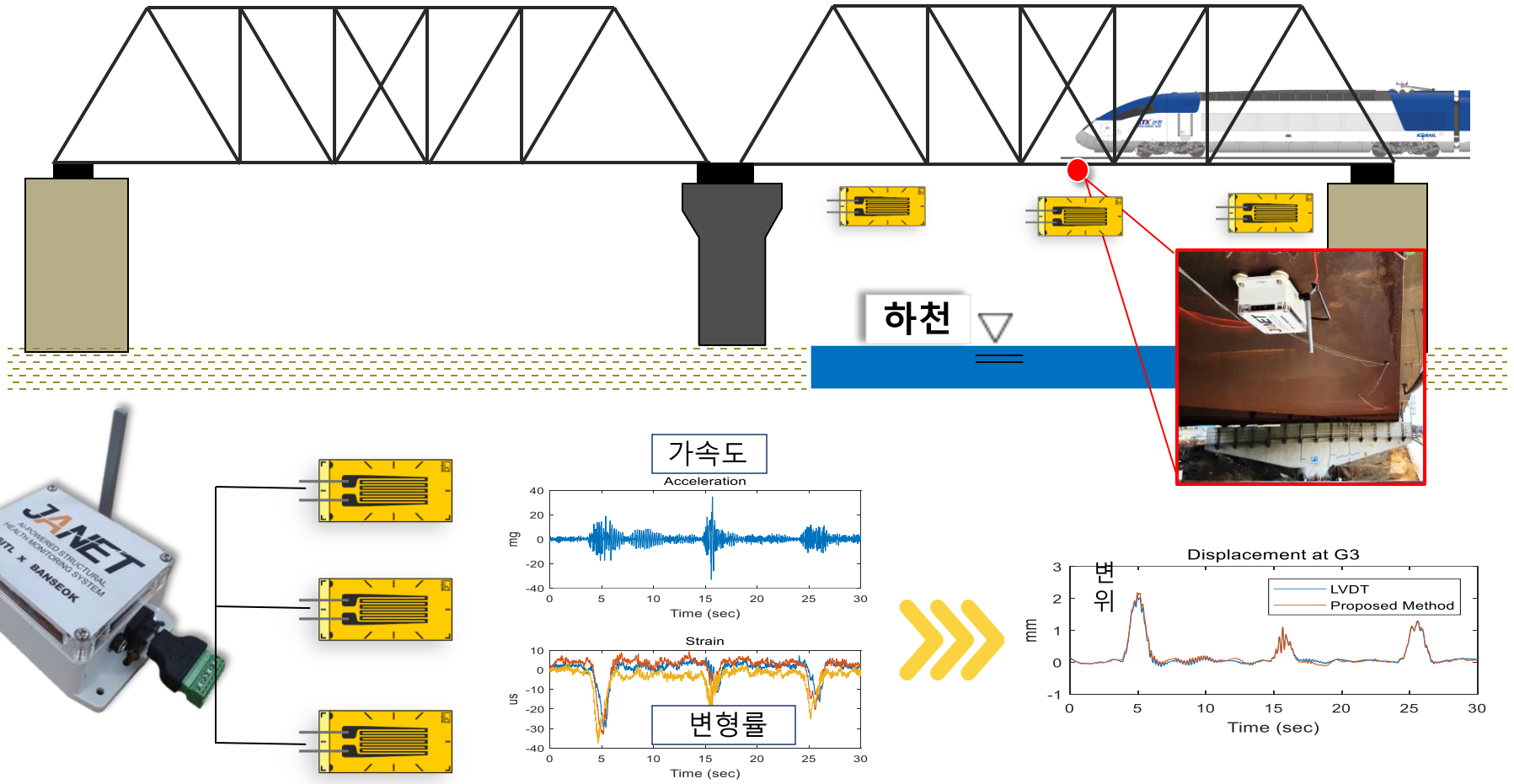
경력

- 스마트 인프라 구조 연구실 Director
- 중앙대학교 부교수 (2021 - 현재)
- 중앙대학교 조교수 (2017 - 2020)
- 일리노이주립대학교 박사 후 연구원 (2014-2017)

스마트 인프라 구조 연구실 (Smart Infrastructure Technology Lab)

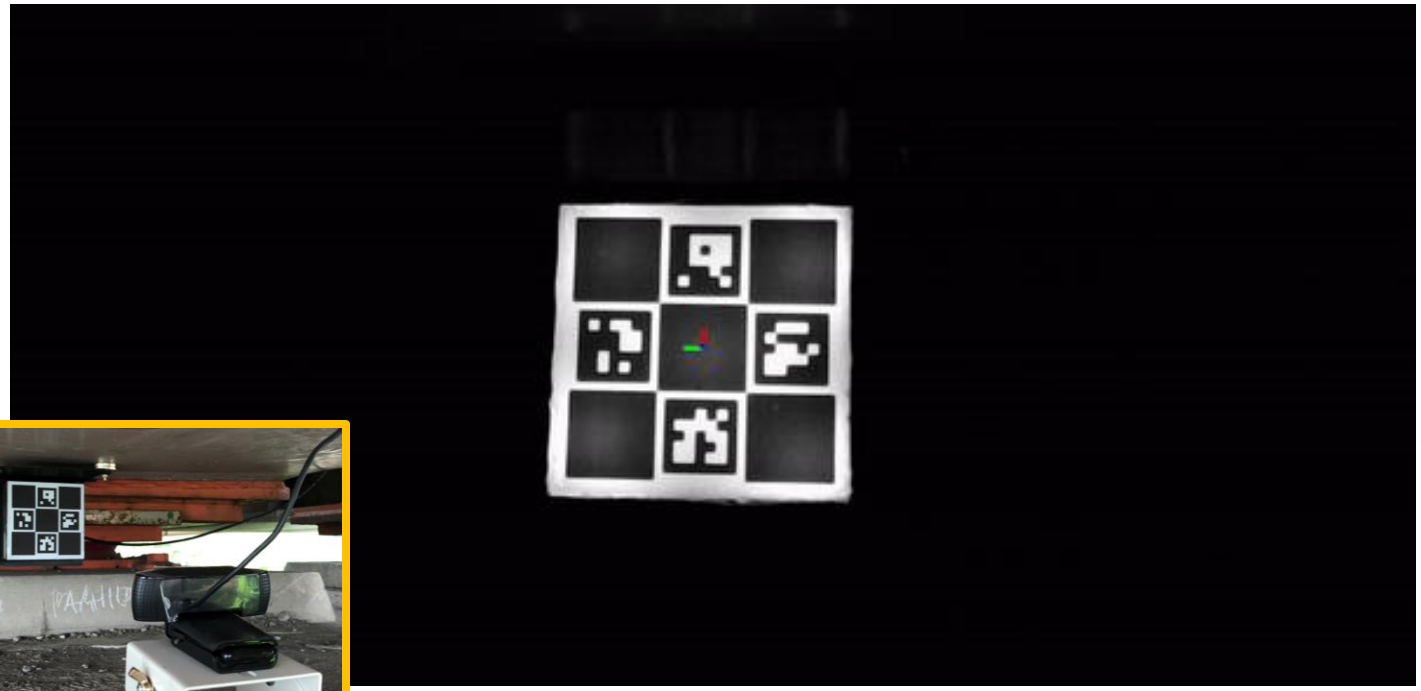


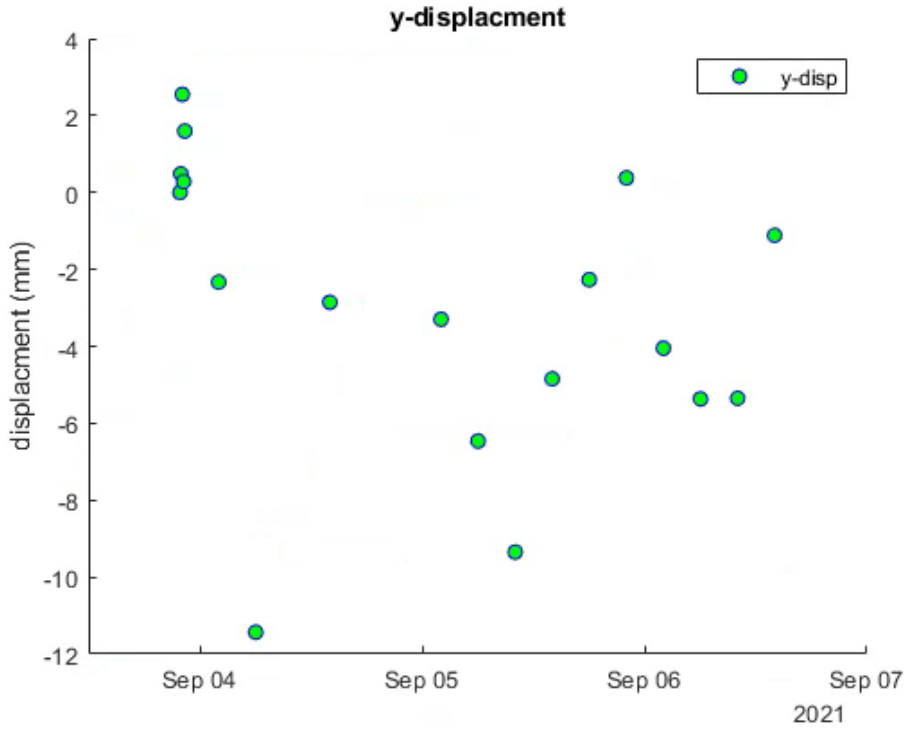
스마트 인프라 구조 연구실 (Smart Infrastructure Technology Lab)



- 가속도 및 변형률 측정이 가능한 센서를 이용하여 기준점이 필요없는 계측 수행
- 모든 교량에 적용이 가능한 교량 변위 측정 시스템
- 건설신기술 (959호) 지정

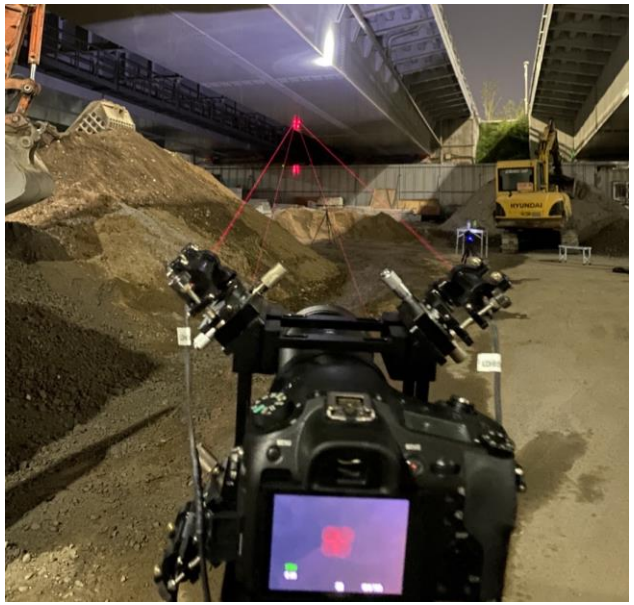
스마트 인프라 구조 연구실 (Smart Infrastructure Technology Lab)

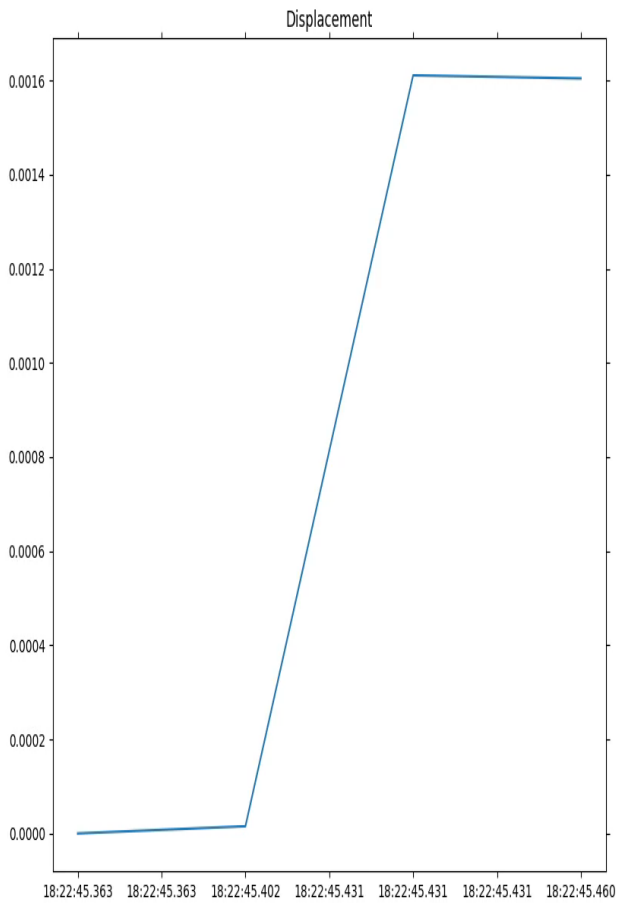




- 교량 하부 받침부 모니터링 시스템
- 클라우드 기반 데이터 관리

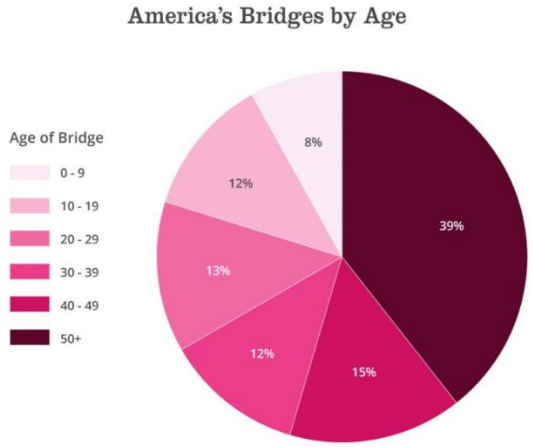
스마트 인프라 구조 연구실 (Smart Infrastructure Technology Lab)

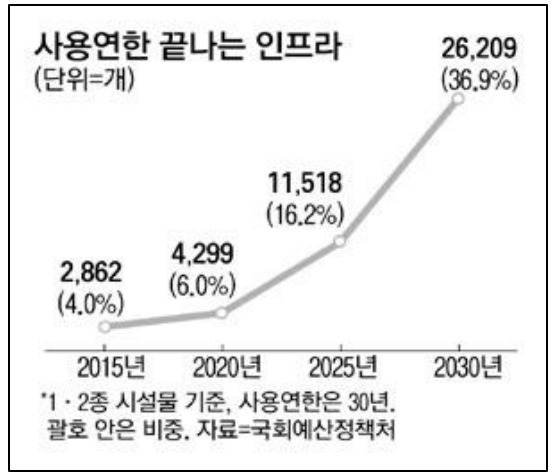




- 원격 구조광 기반 교량 변위 측정 시스템

프로젝트 개요 (Project Overview)





- Manual visual inspection is still currently the main form of assessing the condition of civil infrastructure
- Manual visual inspections dominant
- Korea: inspections every 1-3 years
- 9 IDOT districts perform bridge inspections every 18-24 months, equating to inspecting 36-48 bridges/month per district.

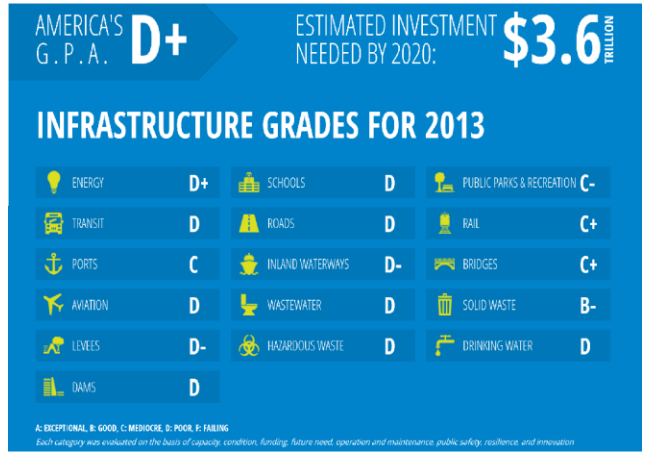
- Over **600,000** highway bridges in the US
- 39% over 50-year design period in the US
- In South Korea, 46% (4,175) of 8,163 bridges are aged, with over 30 years in service.

프로젝트 개요 (Project Overview)

I-35W Bridge, US (2007)

Sungsoo Bridge, Korea (1994)

Jungja Bridge, Korea (2023)



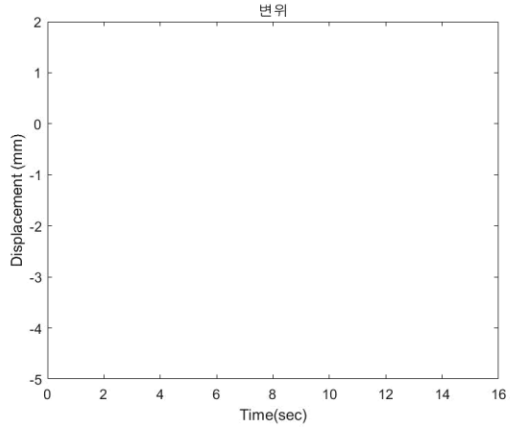
Kobe Earthquake (M=7.2, 1995)
Casualty: 6,308, Damage: $100Billion

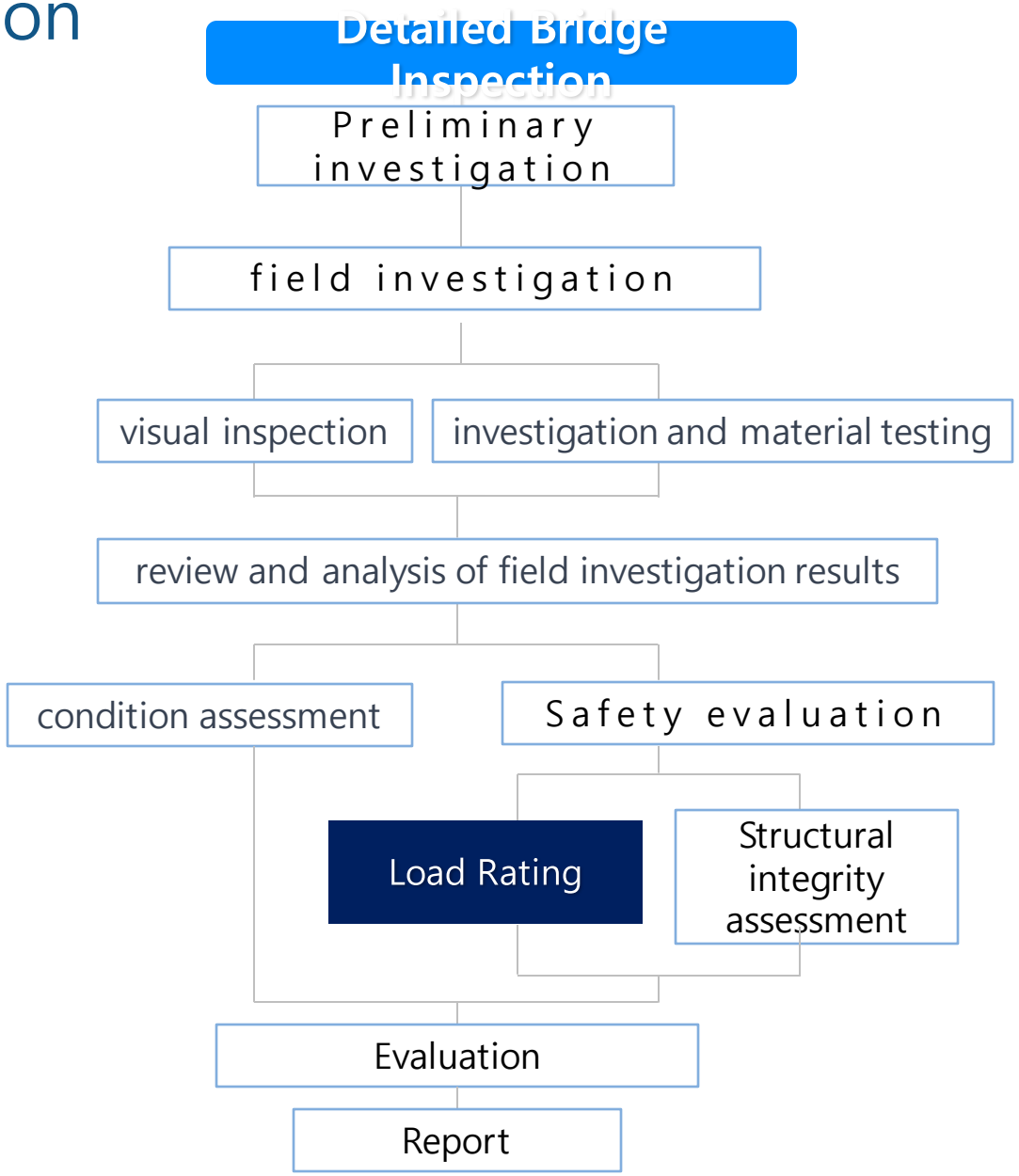
Typhoon in Korea (2003)
Casualty: 135, Loss: $5Billion

Hurricane Katrina in the US (2005)
Casualty: 2,541, Loss: $100Billion

Current Practice of Bridge Inspection

종류 안전등급	A 등급	B·C 등급	D·E 등급
정기안전점검	반기에 1회 이상	반기에 1회 이상	1년에 3회 이상
긴급안전점검	재난 또는 재해 발생 우려 있는 경우	재난 또는 재해 발생 우려 있는 경우	재난 또는 재해 발생 우려 있는 경우
정밀안전진단	6년에 1회 이상	5년에 1회 이상	4년에 1회 이상





Bridge Load Rating

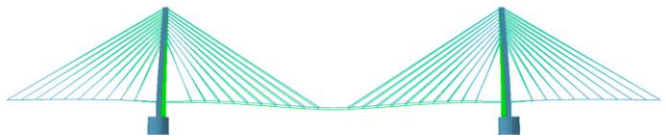
- The Rating Factor (RF) is useful in understanding the factor of safety on the bridge

$$RF^{*} = \frac{R-D}{L(1+i)} Ks$$

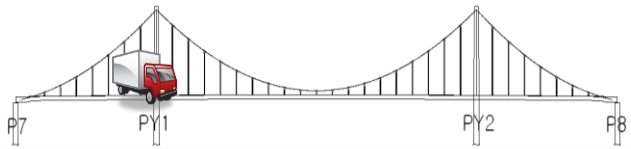
RF: Rating Factor for live load capacity
R: Load the bridge can safely carry
D: Dead load of the bridge
L: Live load due to the rating trick model
i: Impact factor

Compensation Factor $Ks = \frac{\delta_{FEM}}{\delta_{Measured}} \times \frac{1 + i_{FEM}}{1 + i_{Measured}}$

Reflect current status of measurement into calculation



Displacement from FE Model

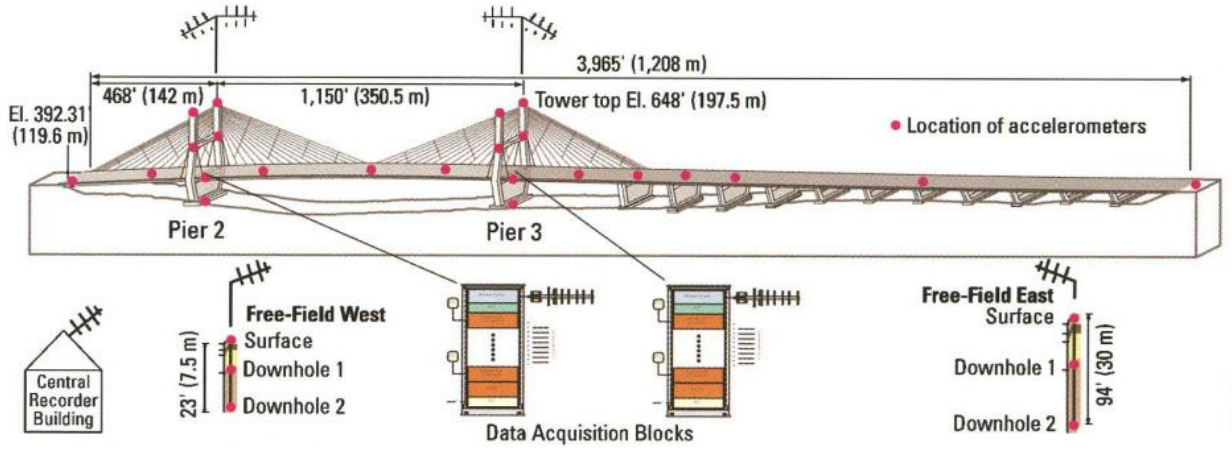


Actual Measured Displacement

*National Bridge Inspection Standards

Sensing-based SHM

Cabling & instrumentation for 400 wired strain sensors

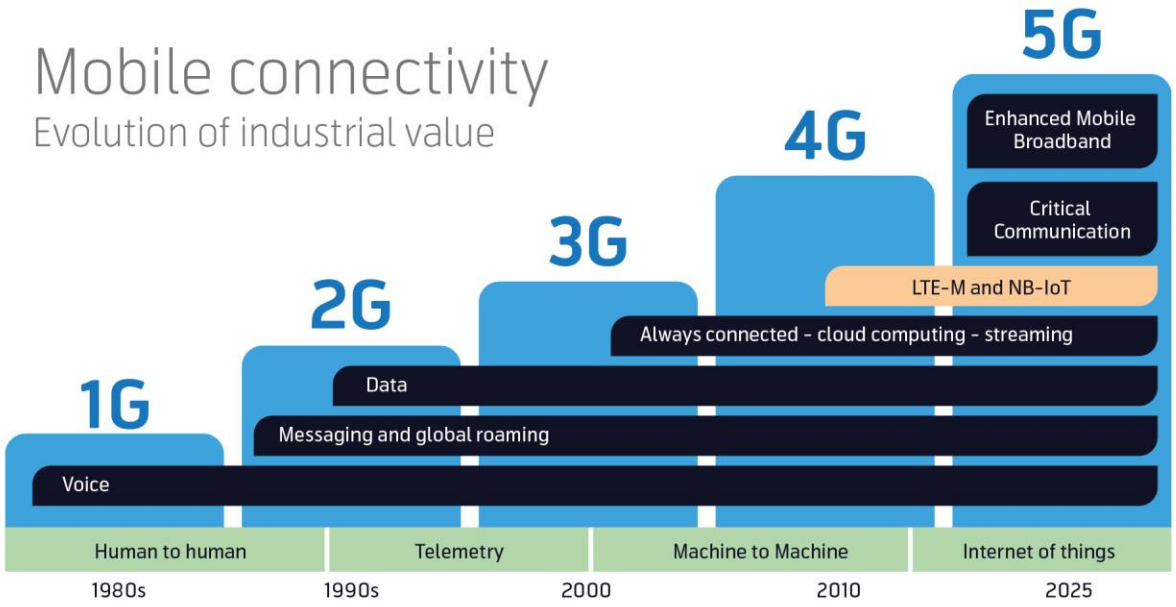


Bill Emerson Memorial Bridge SHM system
$1.3M for 86 sensors, $15k/sensor
(Caicedo et al. 2002; Celebi et al. 2004)

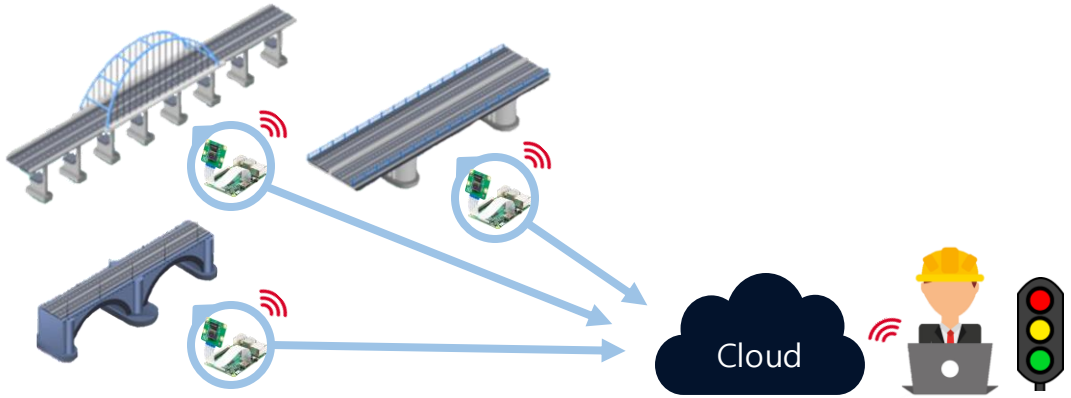
- Proper SHM technology must be applied for preemptive and predictive management
- Expensive wired monitoring systems
- Not scalable to dense-array of sensors
- Generally single-metric measurement

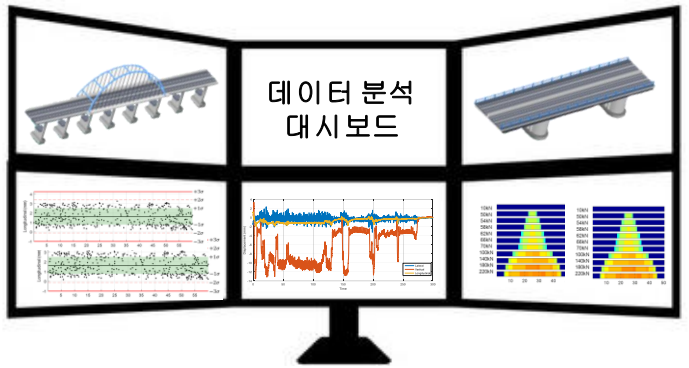
Opportunity

aws Azure Google Cloud



Cloud-based Real-time Bridge Monitoring





1. 스마트 센서

2. 클라우드 시스템

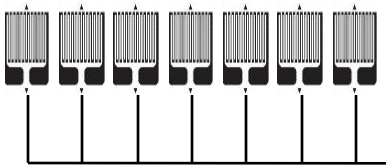
기술적인 해결과제

1. Smart Sensor

2. Cloud-based System

Hardware Development

Strain gauges



Wheatstone Bridge box

Strain amplifier

Cables

Data acquisition device

Leaf sensor nodes

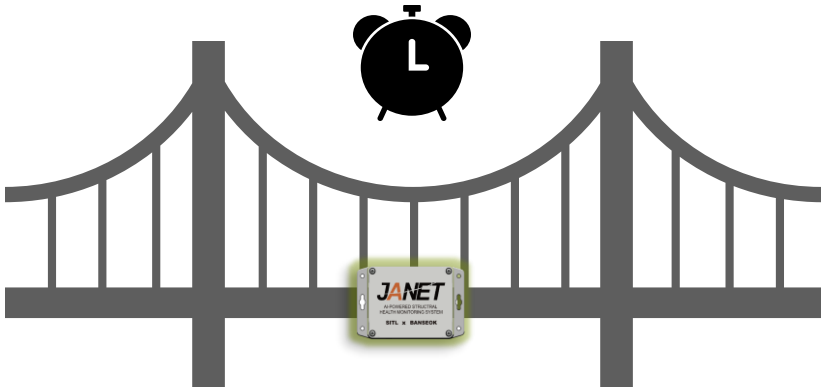
Gateway node

Low-cost Wireless Smart Sensor

Software Development

Vibration-based Trigger

설정 이상 진동 발생 시 계측



Timer-based Trigger

정해진 시간에 깨어 계측

Current Practice of Sensing-based SHM


Waspmote

V-link


Imote2


Martlet

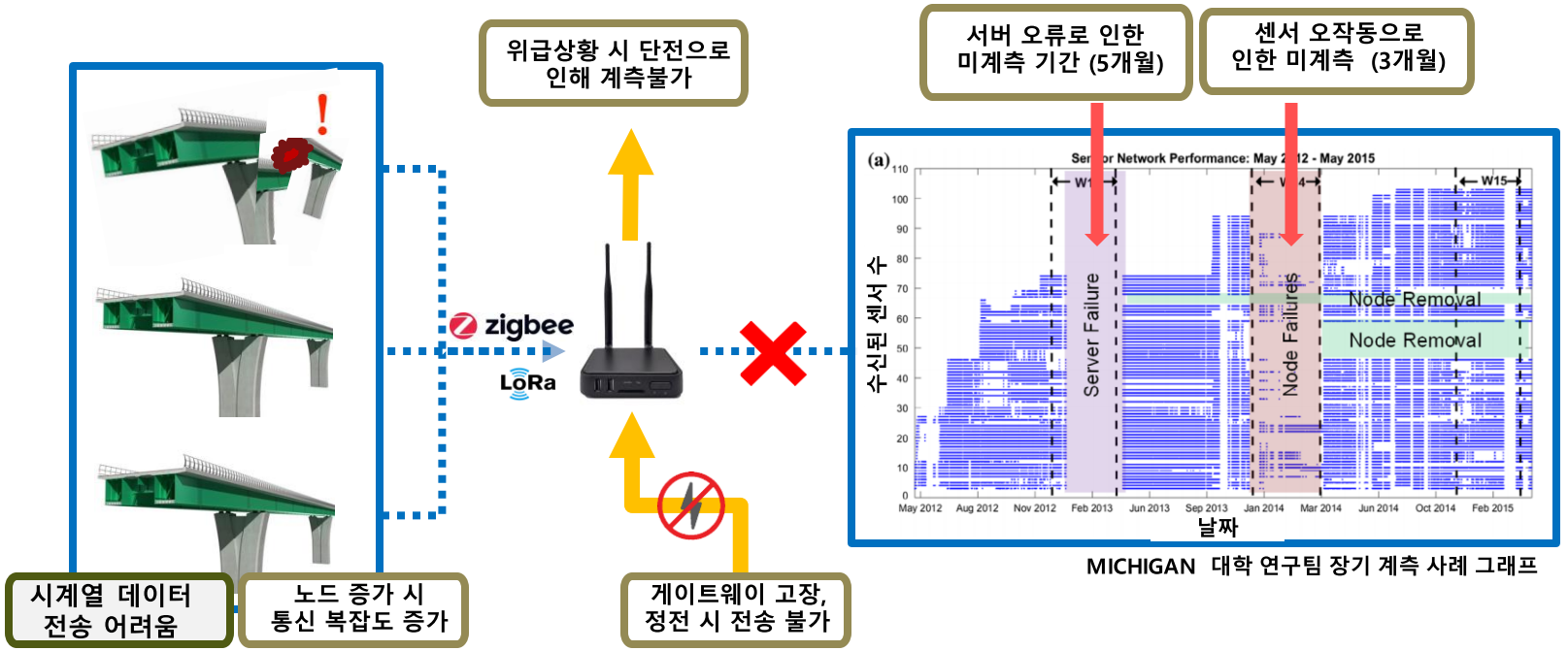

Xnode

JANET

Platform	Maximum Processor Frequency (MHz)	Data Storage	Radio Range	ADC Resolution (bits)	Number of Sensing Channels	Sampling Rate	Energy Harvesting
WaspMote	14	2GB	7 km	-	7	-	O
V-Link	N/A	4 MB	2 km	16	7	10kHz	X
iMote2	416	-	300 m	-	-	-	O
Martlet	80	32GB	>500 m	12	9	3kHz	X
Xnode	204	4GB	1 km	24	8	16kHz	O
JANET*	600	128GB	LTE	24	8	1kHz	O

*Breezy.info.service@gmail.com

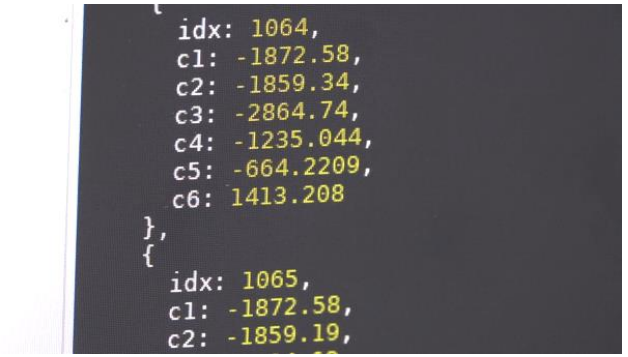
Software Development



MICHIGAN 대학 연구팀 장기 계측 사례 그래프

- 기존 **IoT** 센서에 자주 쓰이던 **Zigbee, Lora, bluetooth** 통신은 느린 전송속도, 짧은 통신범위, 복잡한 네트워크 구성, 게이트웨이 요구 등의 특징 존재

Cloud System



1. Raw Sensing Data

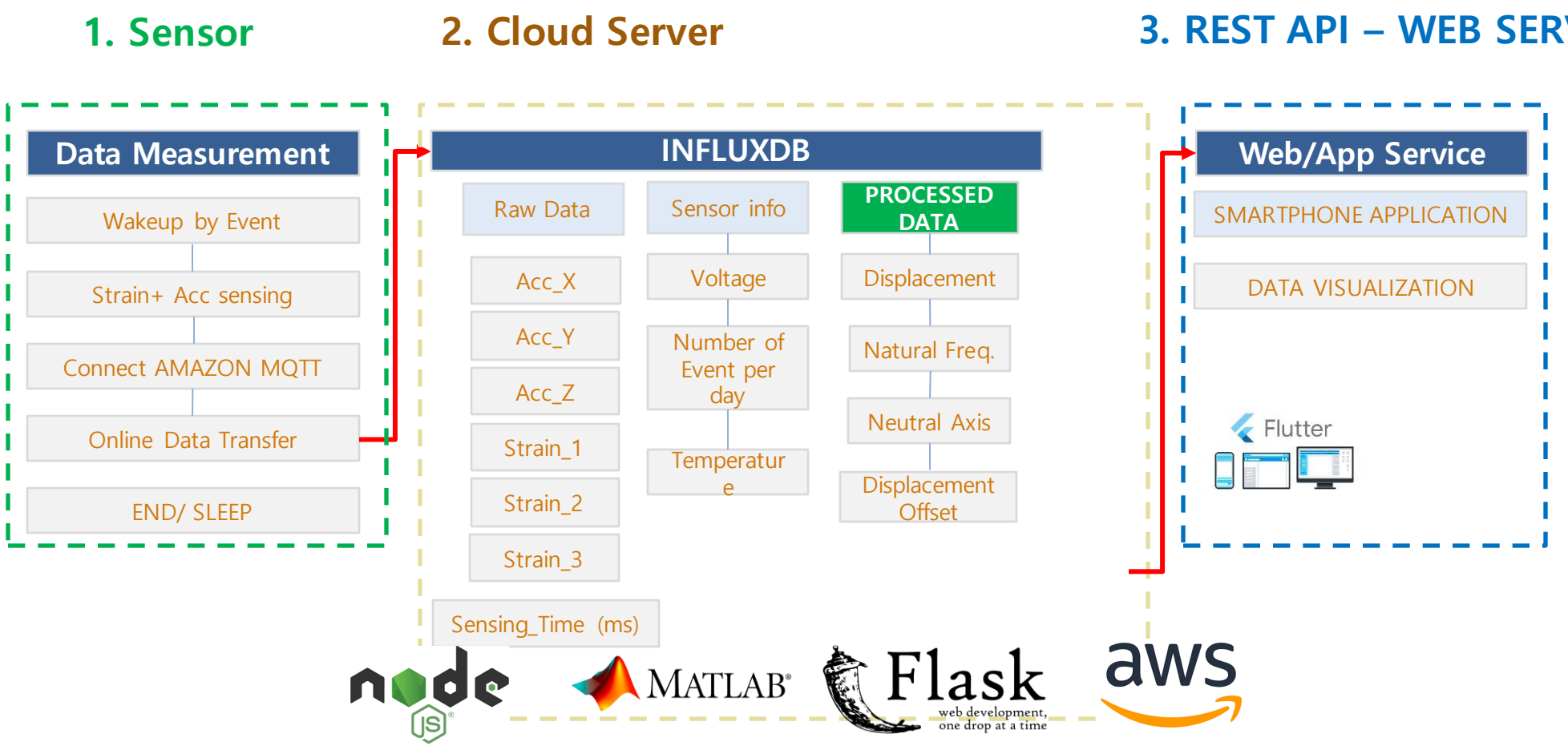
전송완료

2. Database

	sen_idx	event_time	Vbat	isdel	regdt	Vcur	NOE
0	536	2021-10-19 08:03:07	4.111385	N	2021-10-19 08:03:07	0.025634	5.0
1	537	2021-10-19 08:06:23	4.083308	N	2021-10-19 08:06:23	0.022527	4.0
2	538	2021-10-19 08:09:40	4.099788	N	2021-10-19 08:09:40	0.022527	3.0

✓ 트리거 시간, 트리거 횟수, 전압, 전류, 온도, 습도 등 부가 데이터 전송

Cloud System



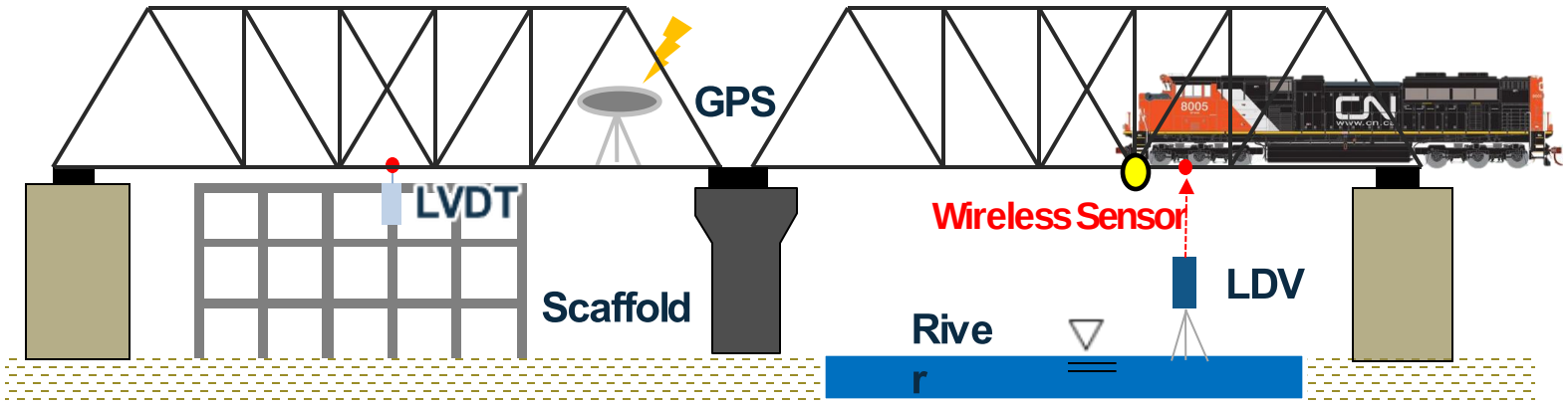
PROCESSING DATA

Cloud computing is Implemented using MATLAB

Cloud Computing

Bridge Displacement

- Therefore, accurate measurement of displacement is crucial for bridge load bearing capacity evaluation.
- However, it always has been inaccurate, difficult, and limited.



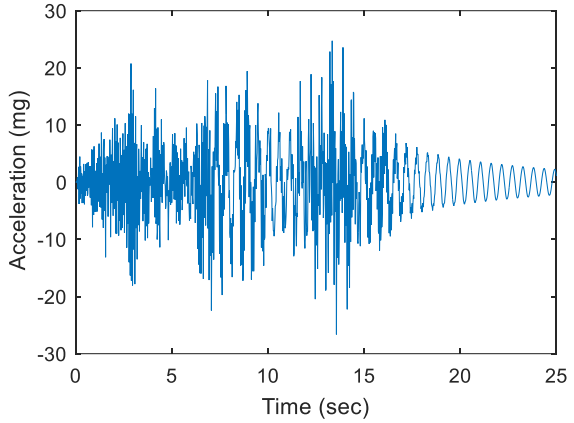
Linear Variable Differential Transformers (LVDT)

Laser Doppler Vibrometer (LDV)

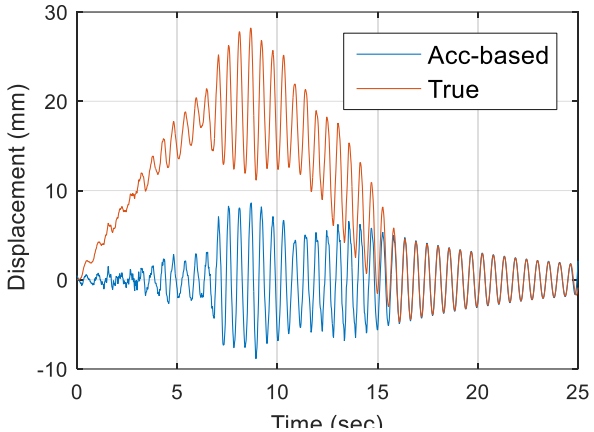
Global Positioning Systems (GPS)

Cloud Computing

Acceleration-based Displacement Estimation

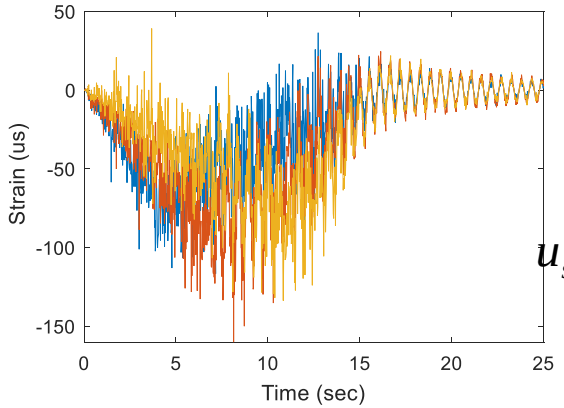


Conversion



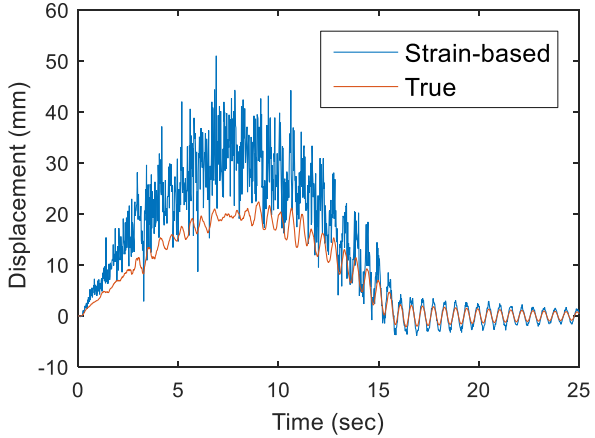
- ✓ *Zero-mean process*
- ✓ Scaling (field calibration required)
- ✓ Require structural model
- ✓ Signal Noise

Strain-based Displacement Estimation



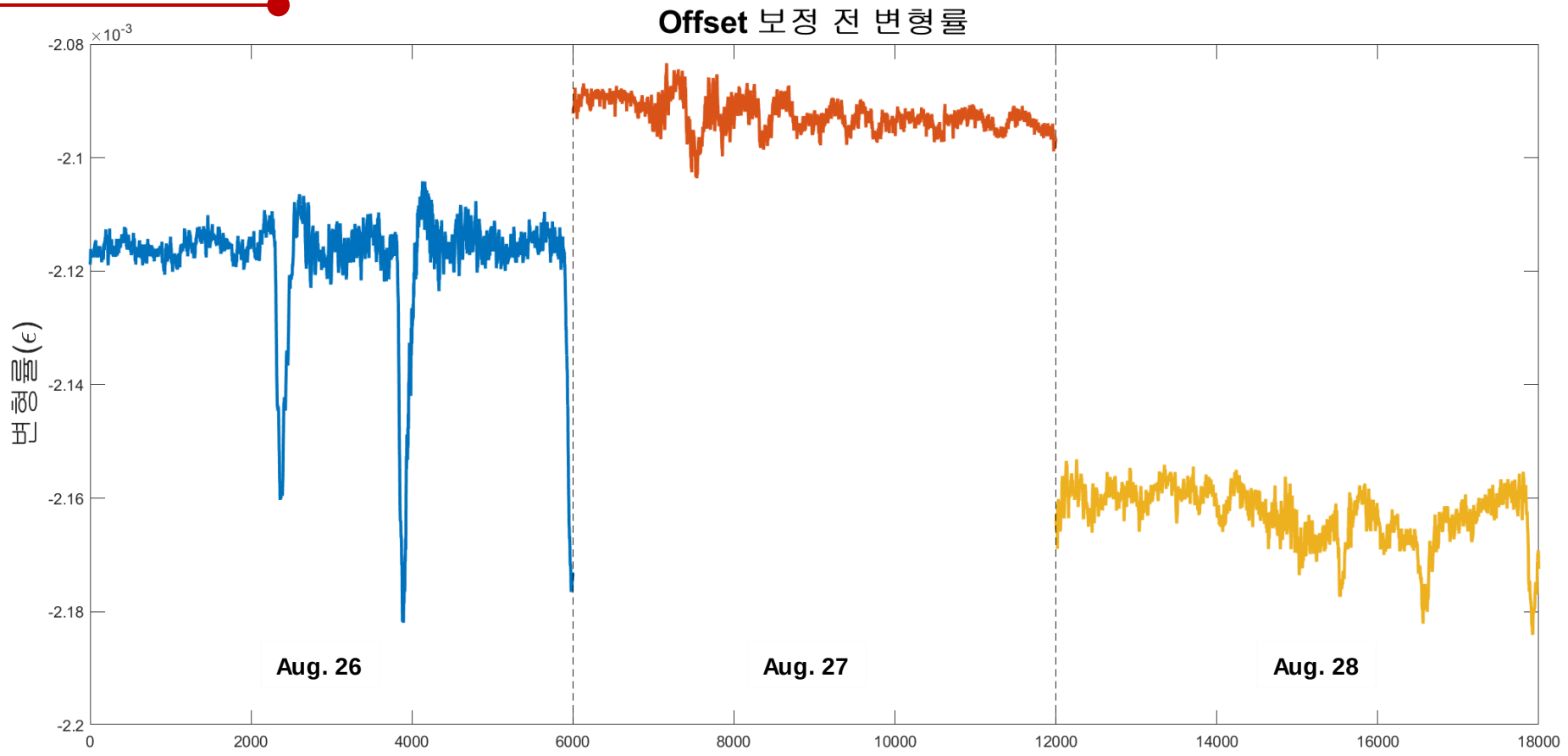
Set of strains into displacement through *modal transformation*

$$u_{strain} = \Phi\Psi^{+}\{\varepsilon\} = \frac{1}{y}\Phi\Phi''^{+}\{\varepsilon\}$$



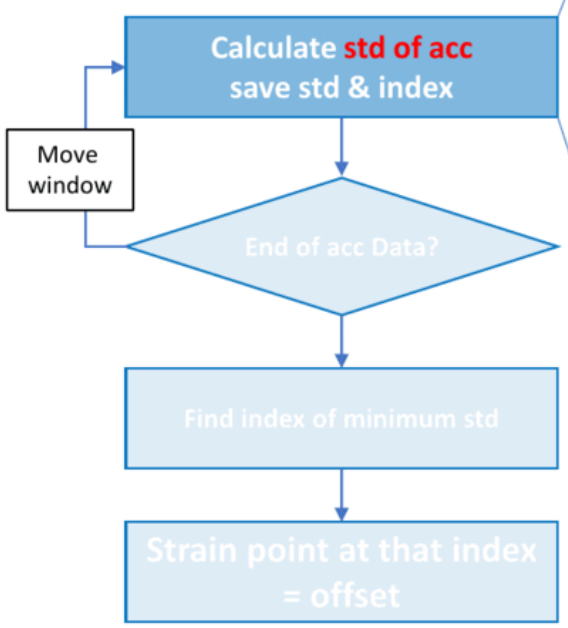
Cloud Computing

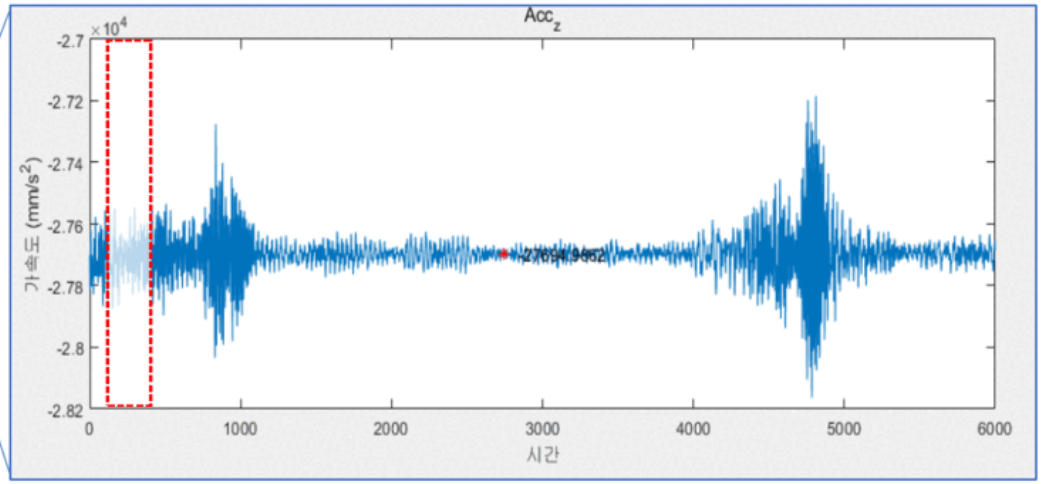
Offset Adjustment



Cloud Computing

Offset Adjustment

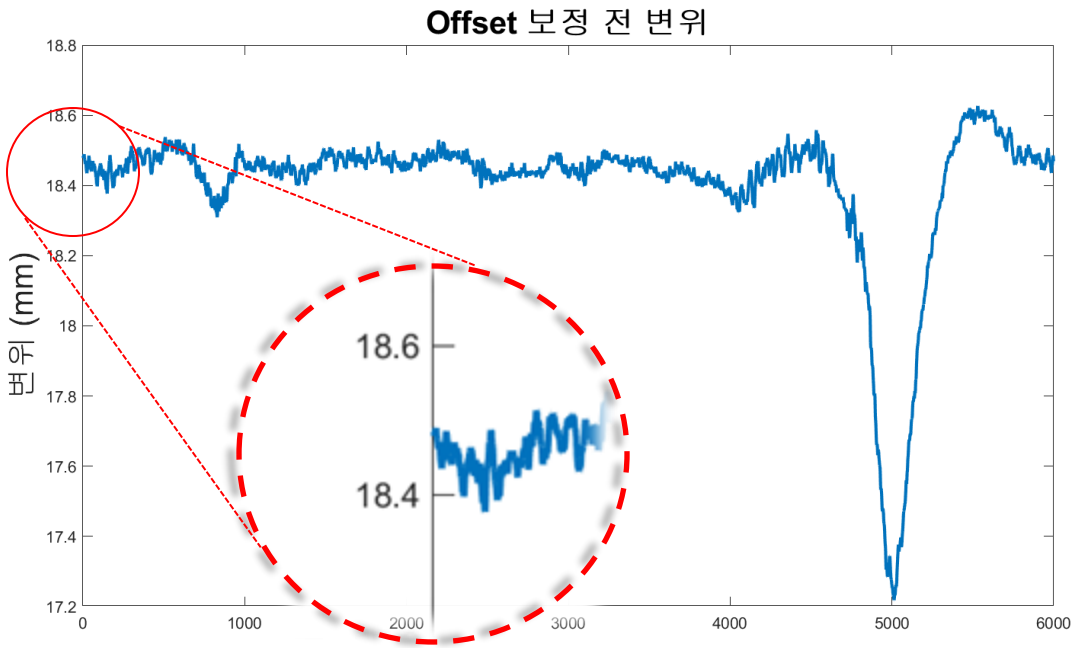




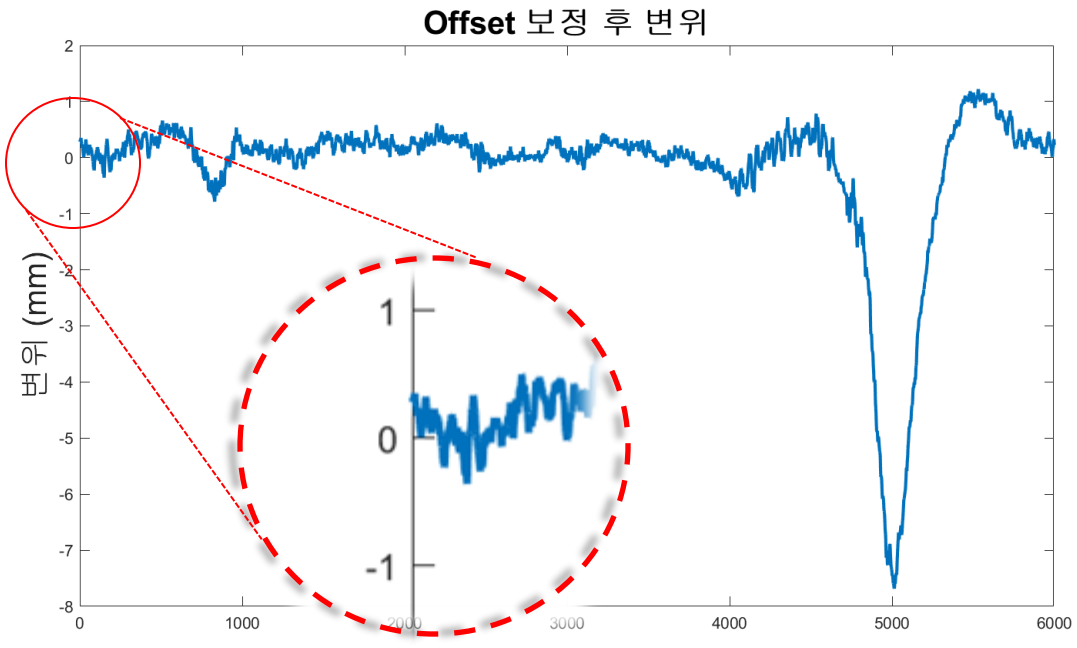
Index	σ_{min}
20	67.7845

Cloud Computing

Offset Adjustment



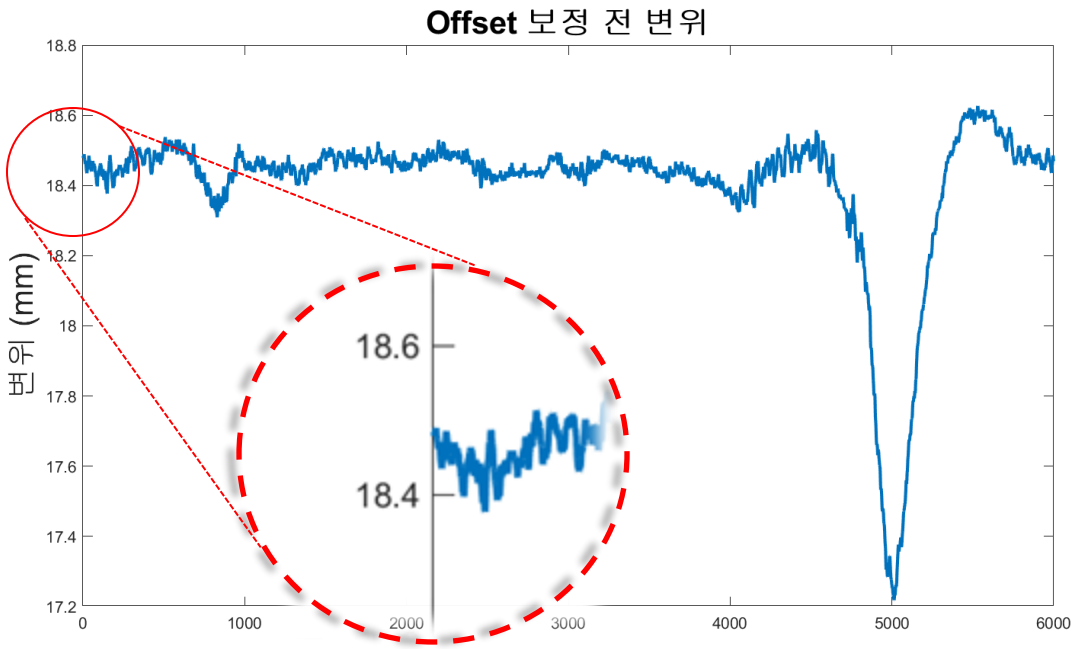
정확한 변위 스케일을 알기 어려움

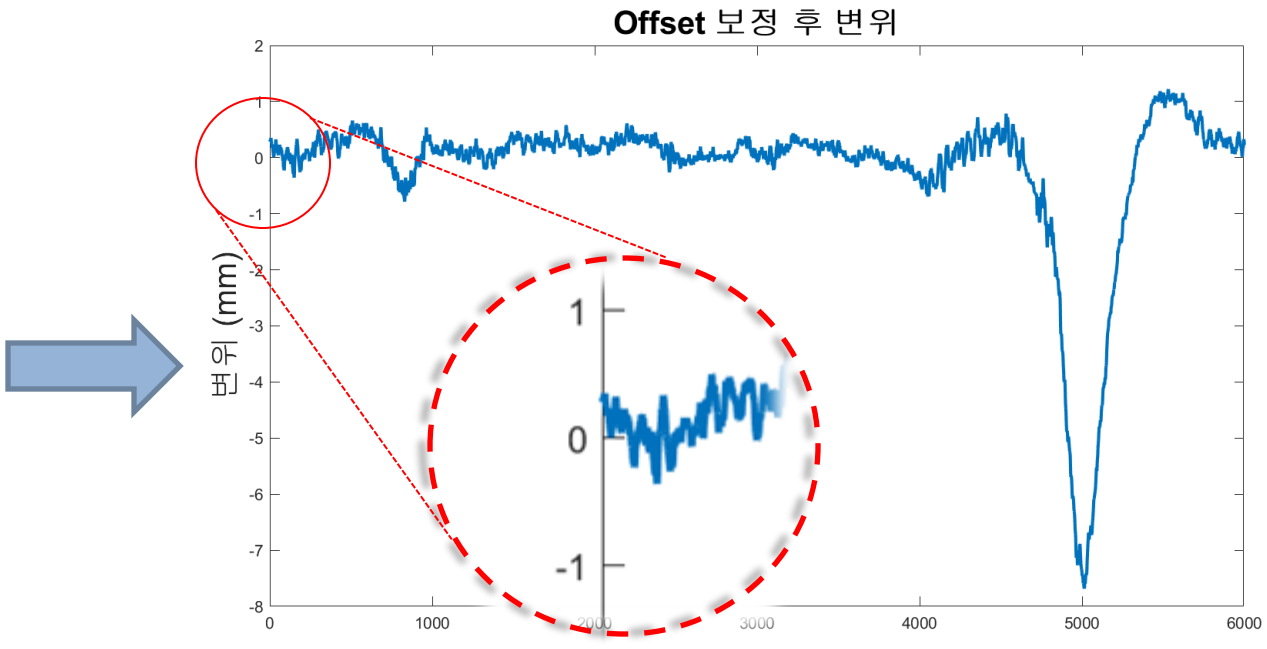


Strain offset 보정 이후 변위 스케일

Cloud Computing

Offset Adjustment



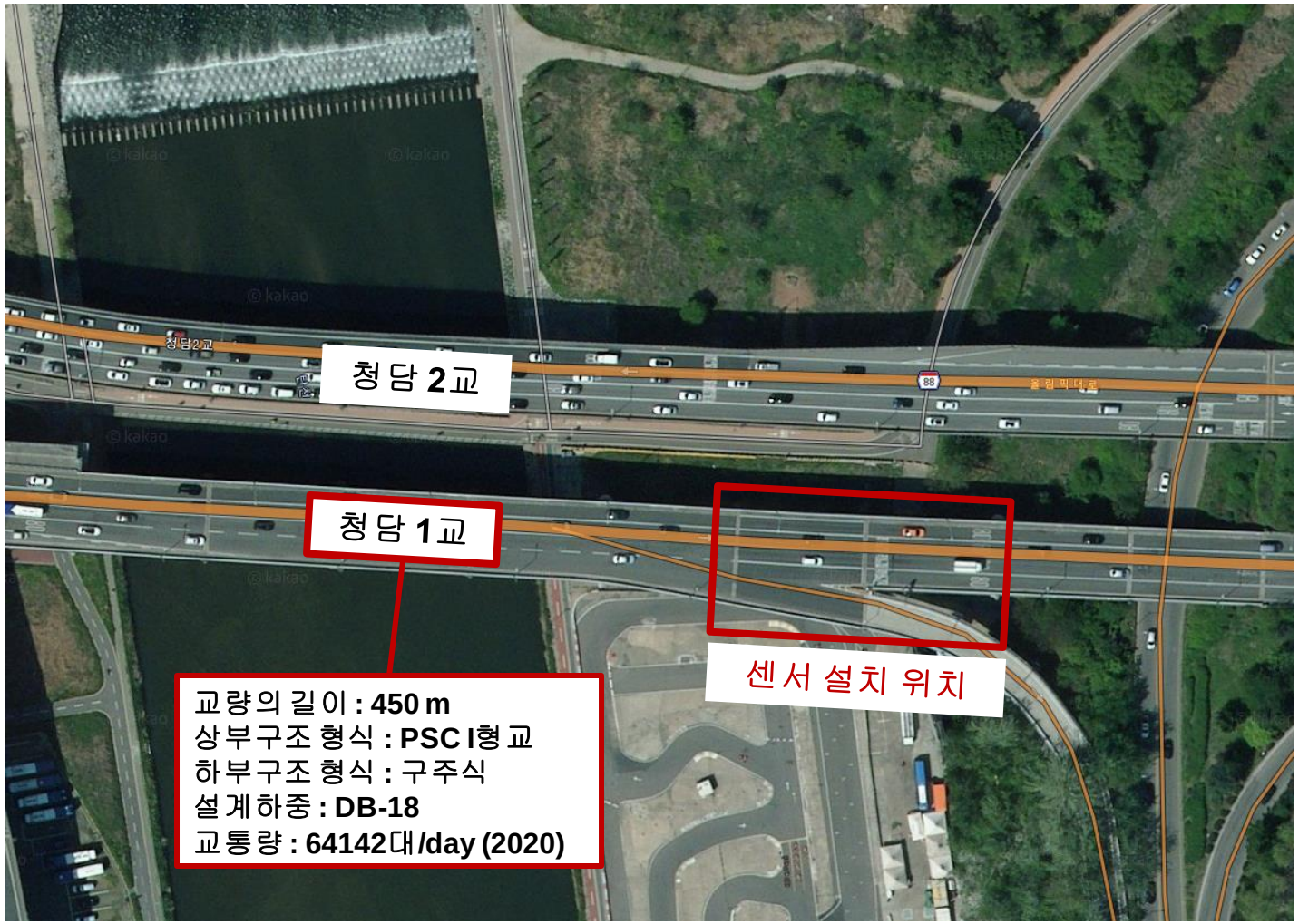


정확한 변위 스케일을 알기 어려움

Strain offset 보정 이후 변위 스케일

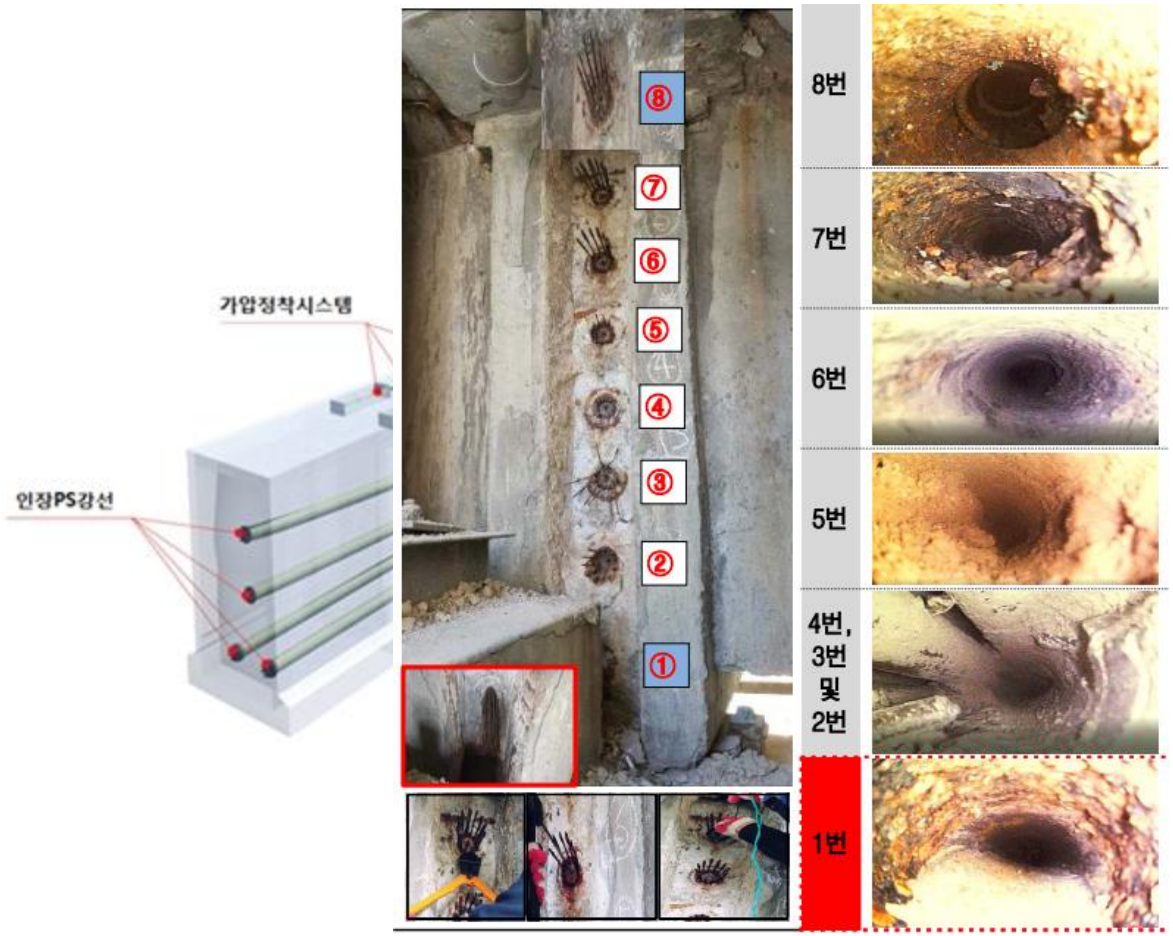
Field Application

Cheongdam 1 Bridge



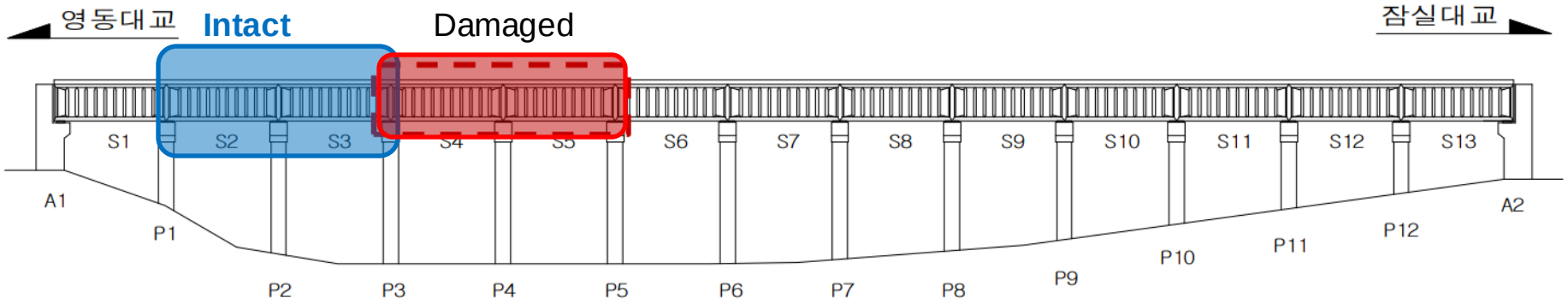
Field Application

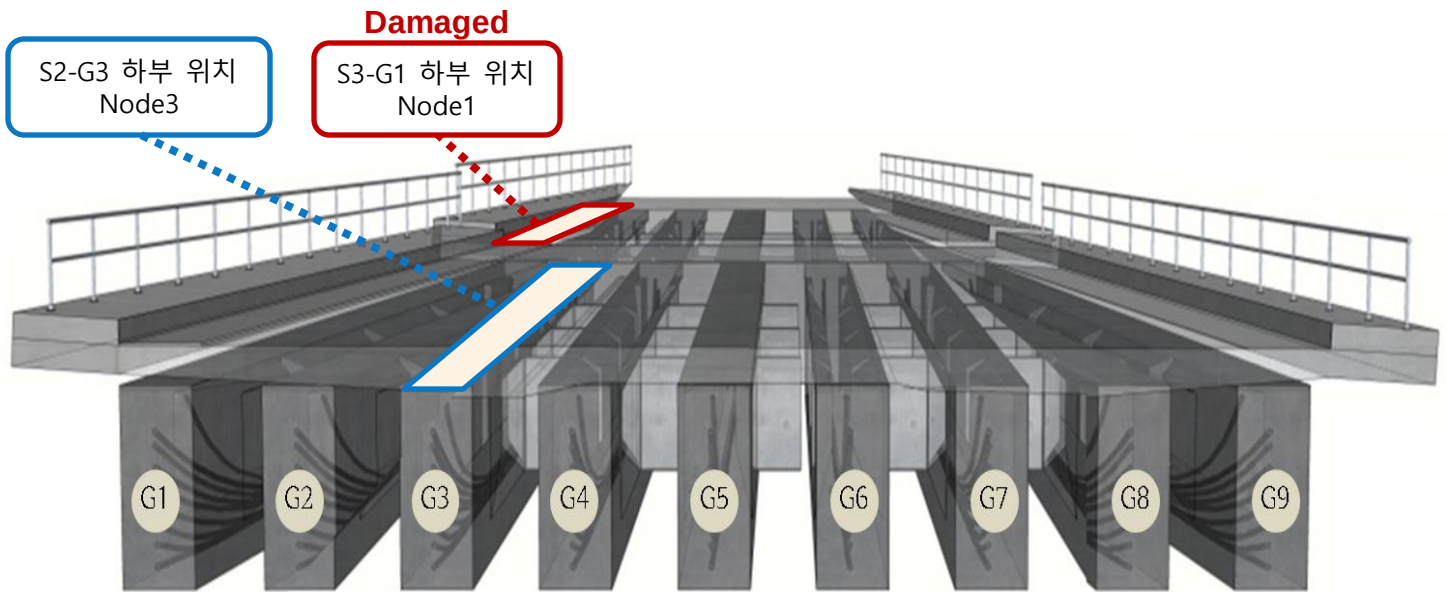
Cheongdam 1 Bridge



Field Application

Cheongdam1 Bridge





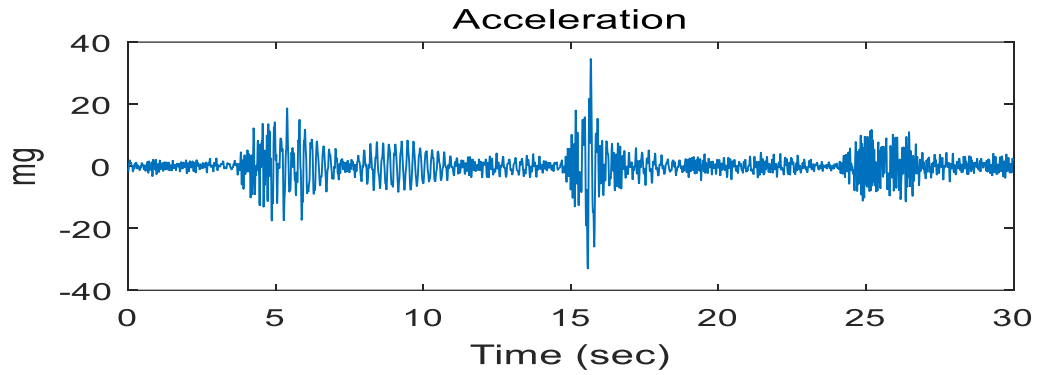
Field Application

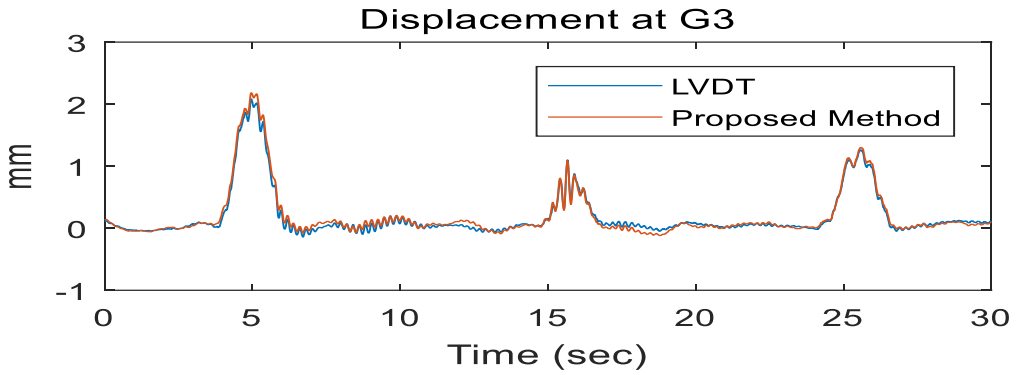
2021-07-23(금)
서울시 청담 1교 센서설치

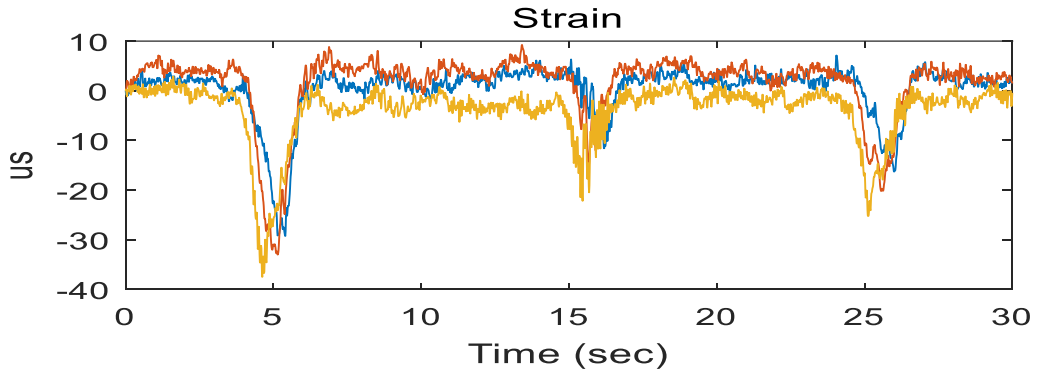
Ring Gauge

Data Analysis

Displacement Measurement



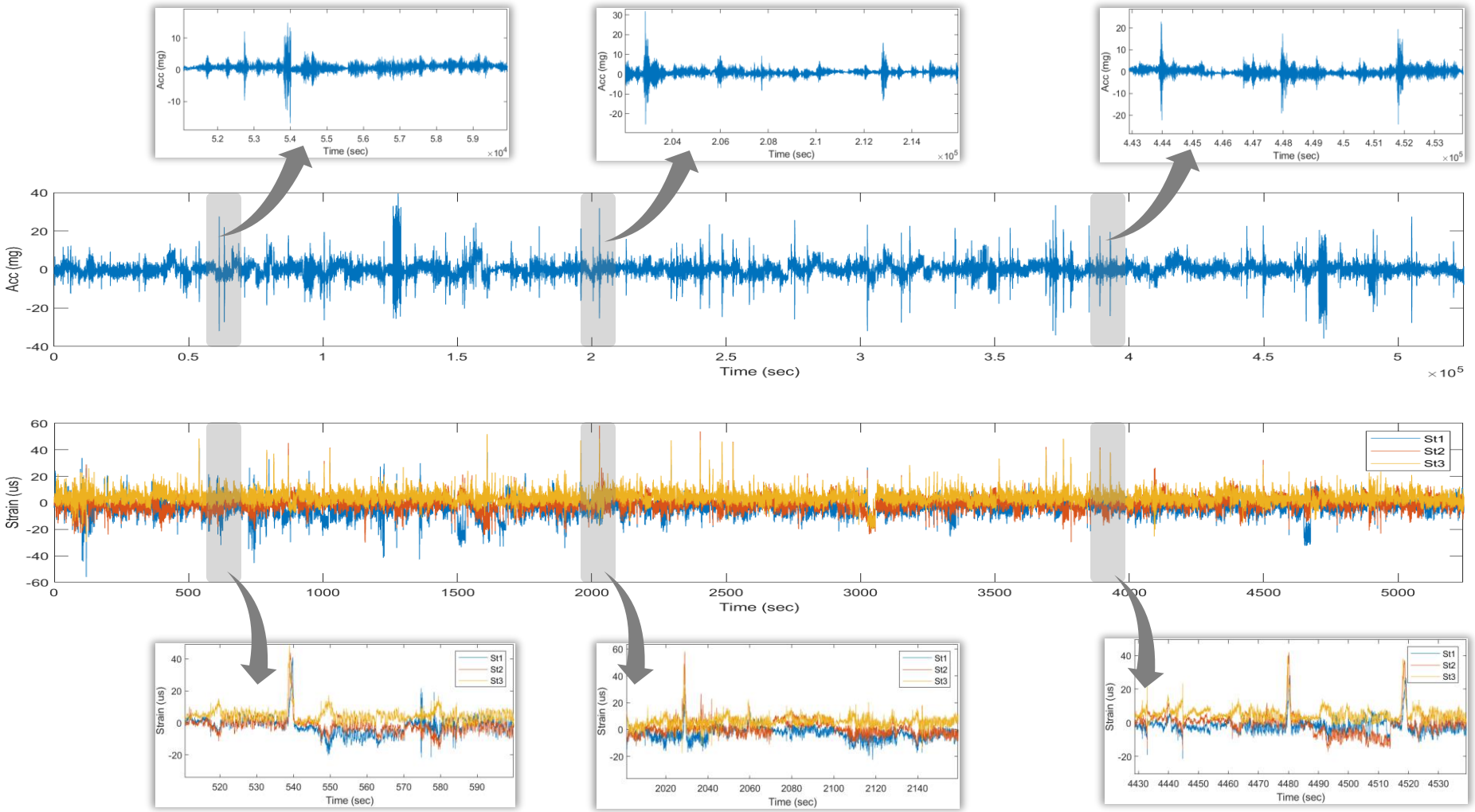




LVDT	JANET	차이
2.08mm	2.18mm	0.1mm
1.01mm	1.09mm	0.08mm
1.26mm	1.31mm	0.05mm

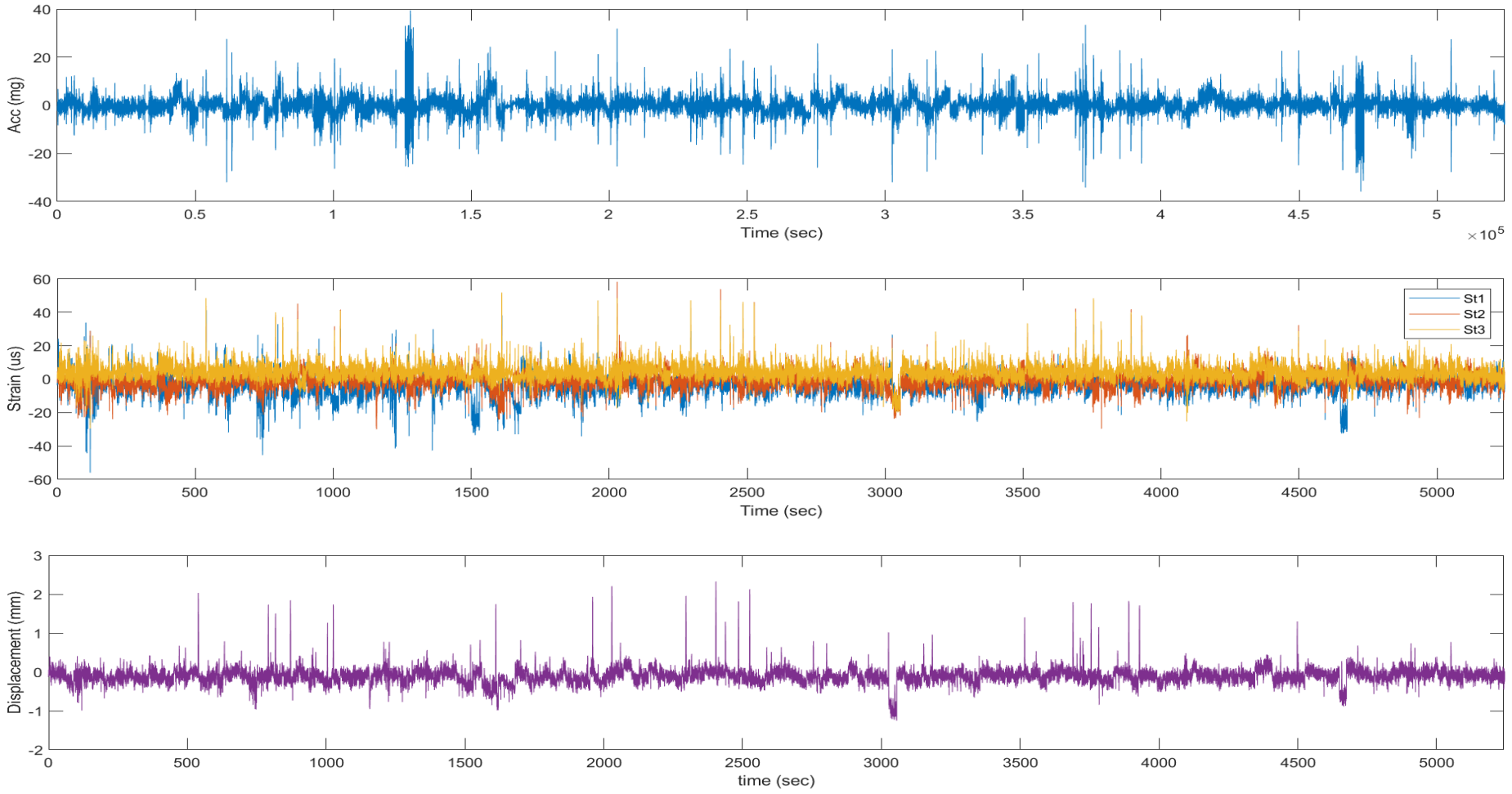
Data Analysis

Raw Data Measurement



Data Analysis

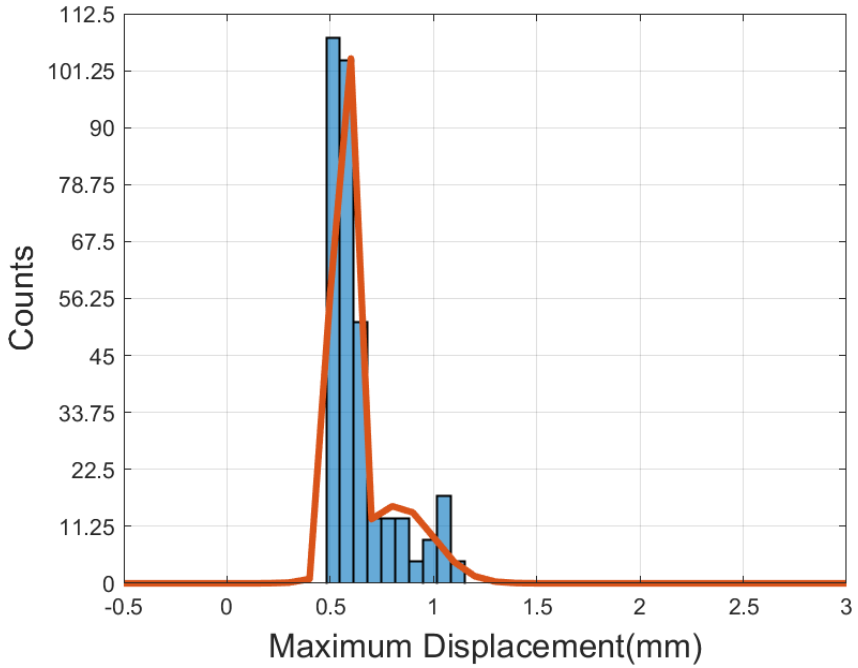
Displacement Conversion



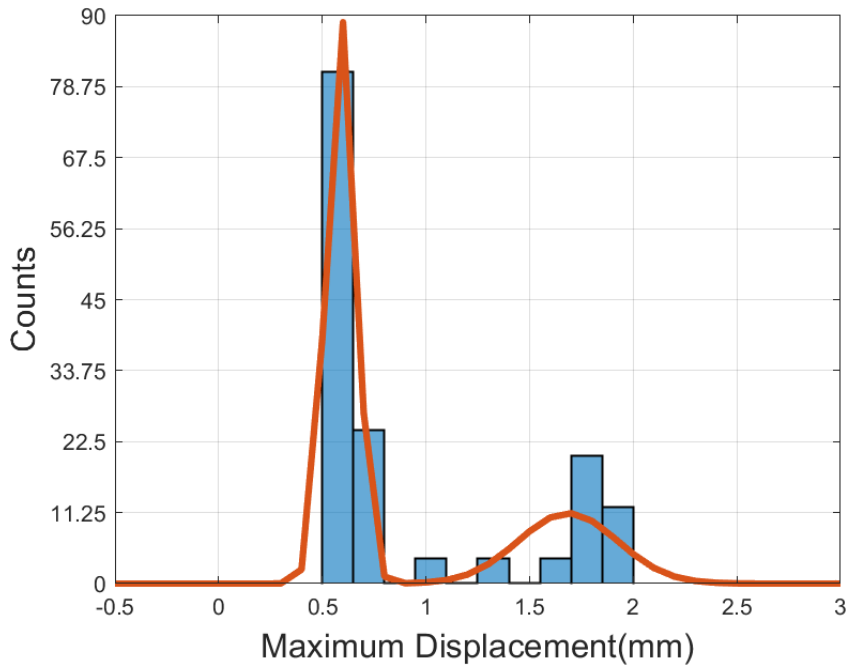
Data Analysis

Displacement Measurement

S3-G1 Damaged



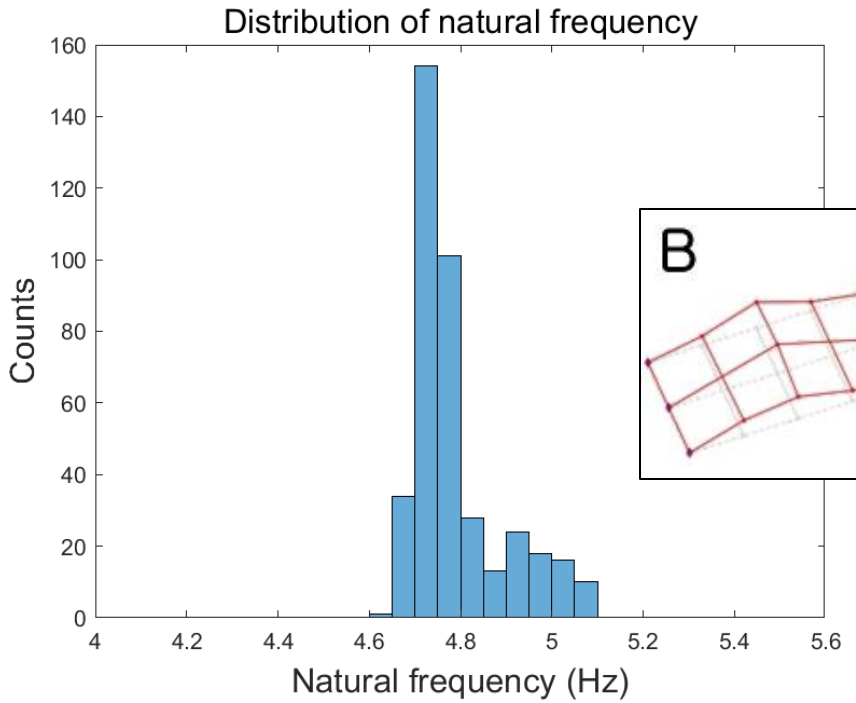
S2-G3 Intact

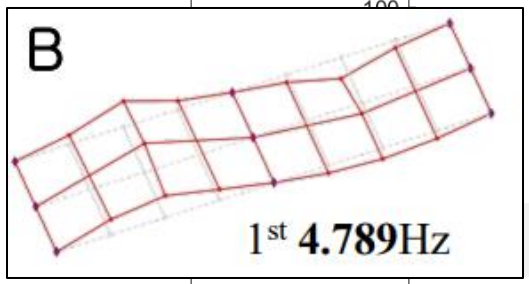


Data Analysis

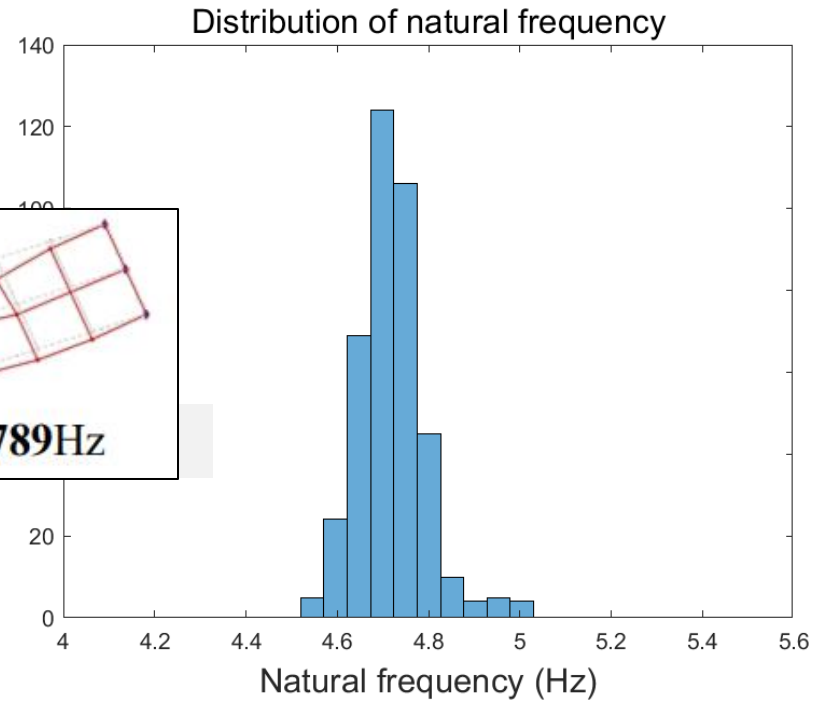
Natural Frequency

S3-G1 Damaged





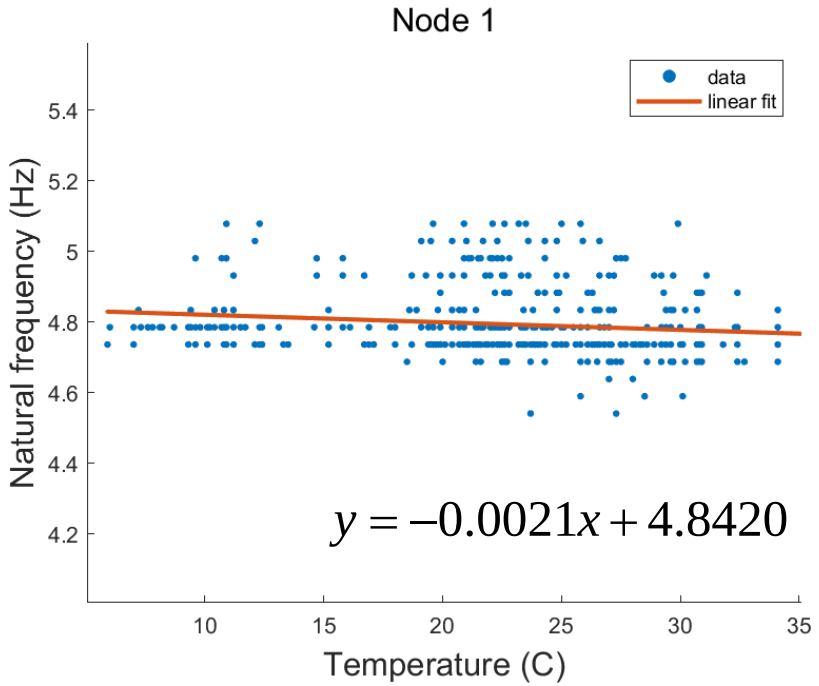
S2-G3 Intact



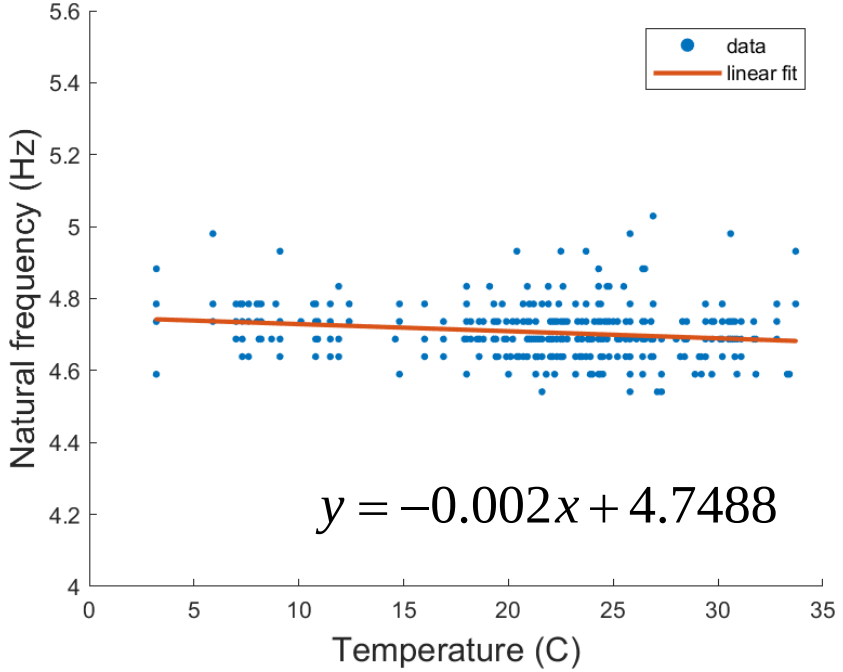
Data Analysis

Natural Frequency

S3-G1 Damaged



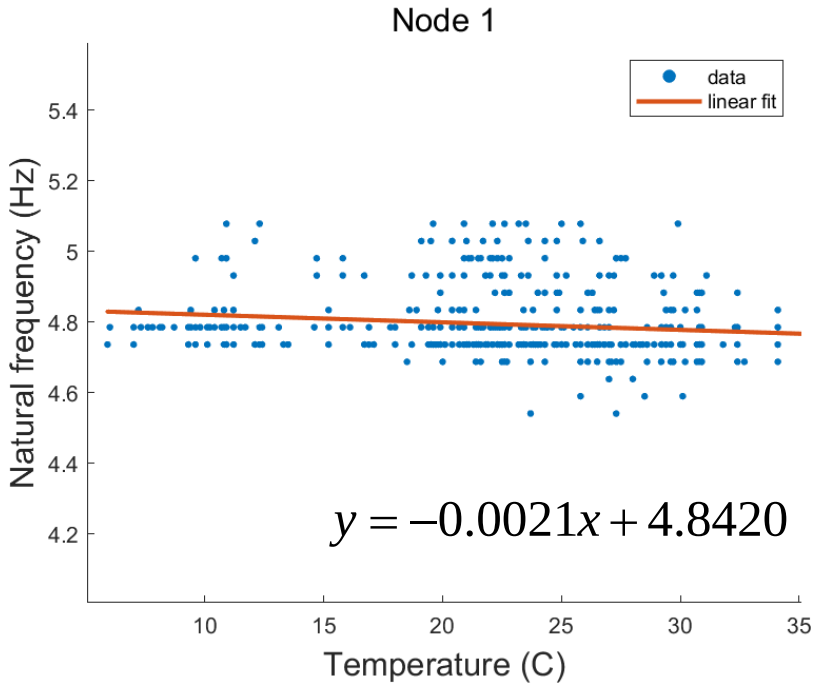
S2-G3 Intact



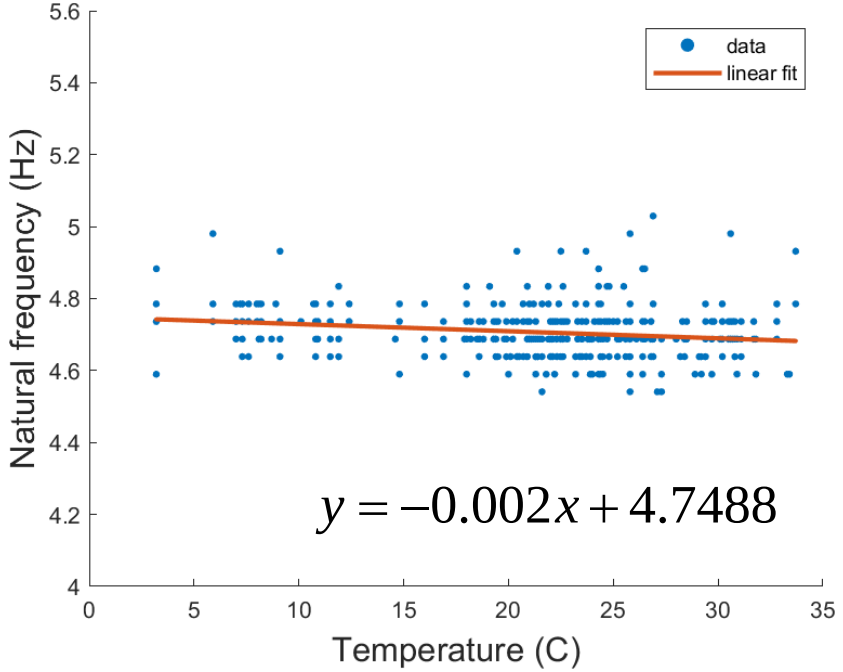
Data Analysis

Natural Frequency

S3-G1 Damaged



S2-G3 Intact



Conclusion

- Proposed cloud-based sensing system improves bridge monitoring by addressing infrequent visual inspection limitations
- JANET, a sensing system designed for long-term multi-channel sensing, was developed to capture bridge motion through strain and acceleration data
- Implemented cloud-based architecture streamlines data processing in bridge monitoring
- Future developments involve incorporating sophisticated data processing algorithms for tailored monitoring solutions

MATLAB EXPO

Thank you