WORKING WEEK 2025 AND Locate25 THE NATIONAL GEOSPATIAL CONFERENCE

Collaboration, Innovation and Resilience: Championing a Digital Generation

Brisbane, Australia 6–10 April

High-Rate Bridge Displacement Monitoring with Low-Rate VRS Data

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OUTLINE

- GNSS for structural health monitoring
- Using low-rate VRS data for high-rate displacement monitoring
- Experiments
- Conclusions

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GNSS for structural health monitoring

Using low-rate VRS data for high-rate displacement monitoring

Experiments

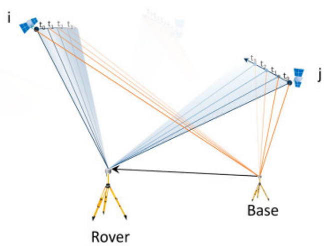
Conclusions

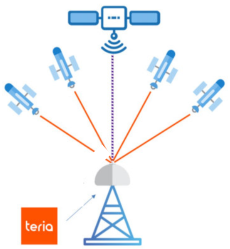
Structural Health Monitoring (SHM)

- There are many different types of structures.
- Structures may fail and impose safety threats.
- Important to monitor structures to understand their health conditions.

GNSS Play an Important Role in SHM

- Accurate 3D displacements.
- Both static and dynamic displacements.
- Real-time.
- All weather.
- High data rate.





- A reference station is required.
- Accuracy decreases with the length of the baseline.
- Construction and maintenance of reference stations involve cost.
- Virtual Reference Station (VRS) method offers a solution but its data rate is often limited.
- This research explores to use low-rate VRS for high-rate displacement monitoring.

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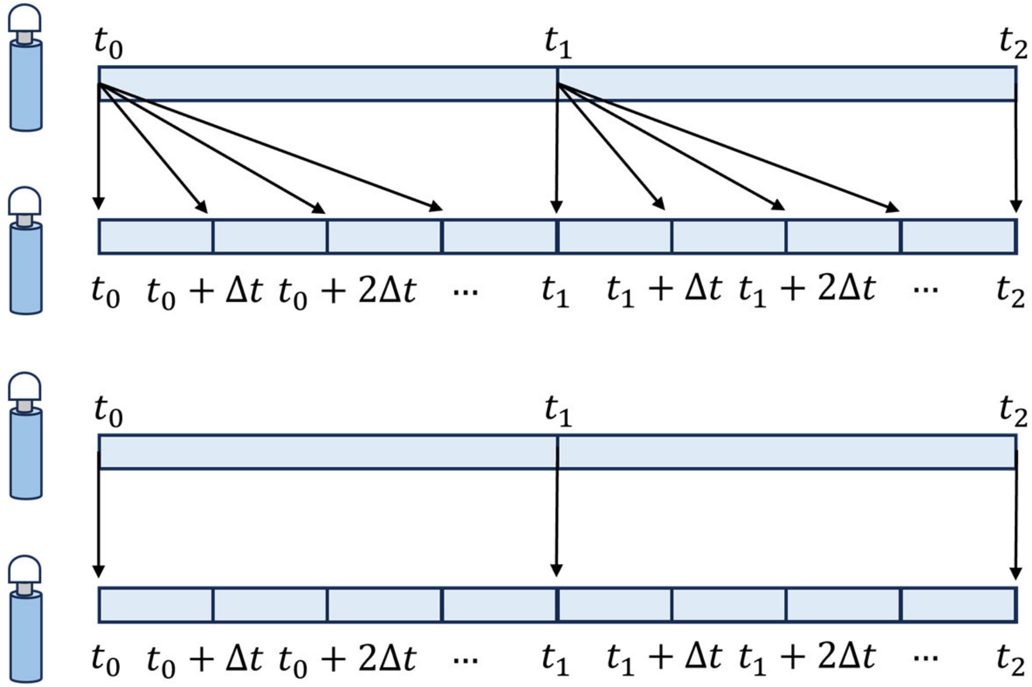
Synchronous and Asynchronous RTK (SRTK & ARTK)



- VRS + asynchronous RTK (VRS-ARTK).
- VRS-ARTK is explored for displacement monitoring.

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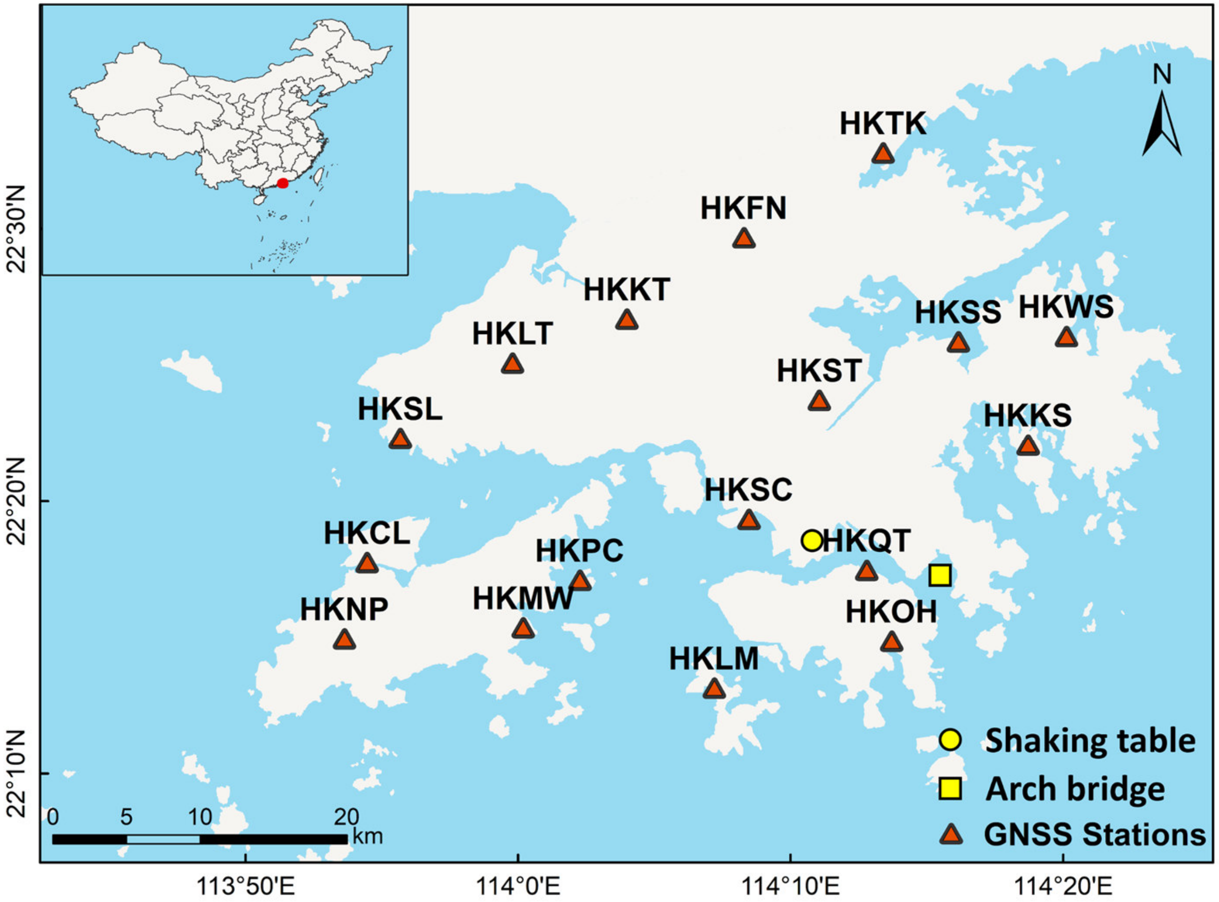
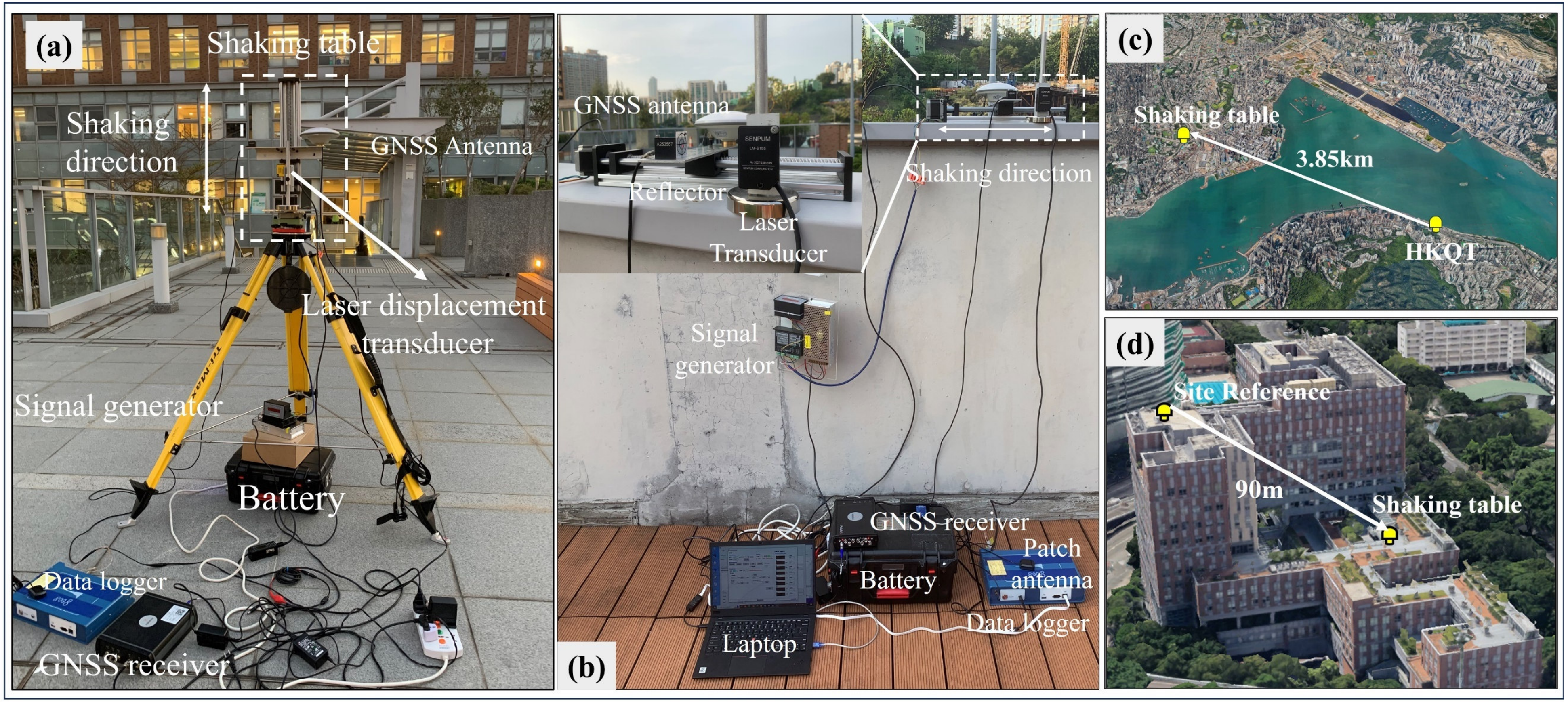
Hong Kong SatRef GNSS Network



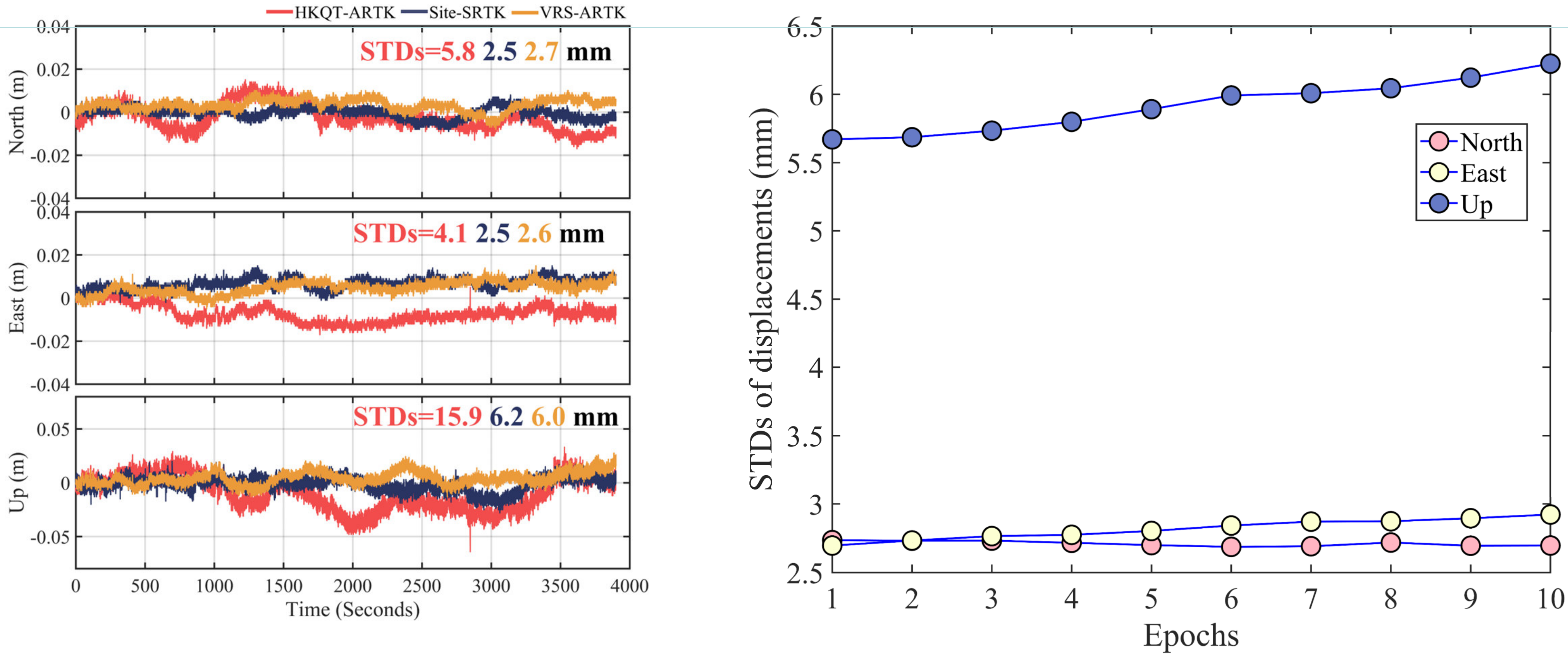
- 17 GNSS stations
- Providing VRS services over whole Hong Kong

Shaking Table Test



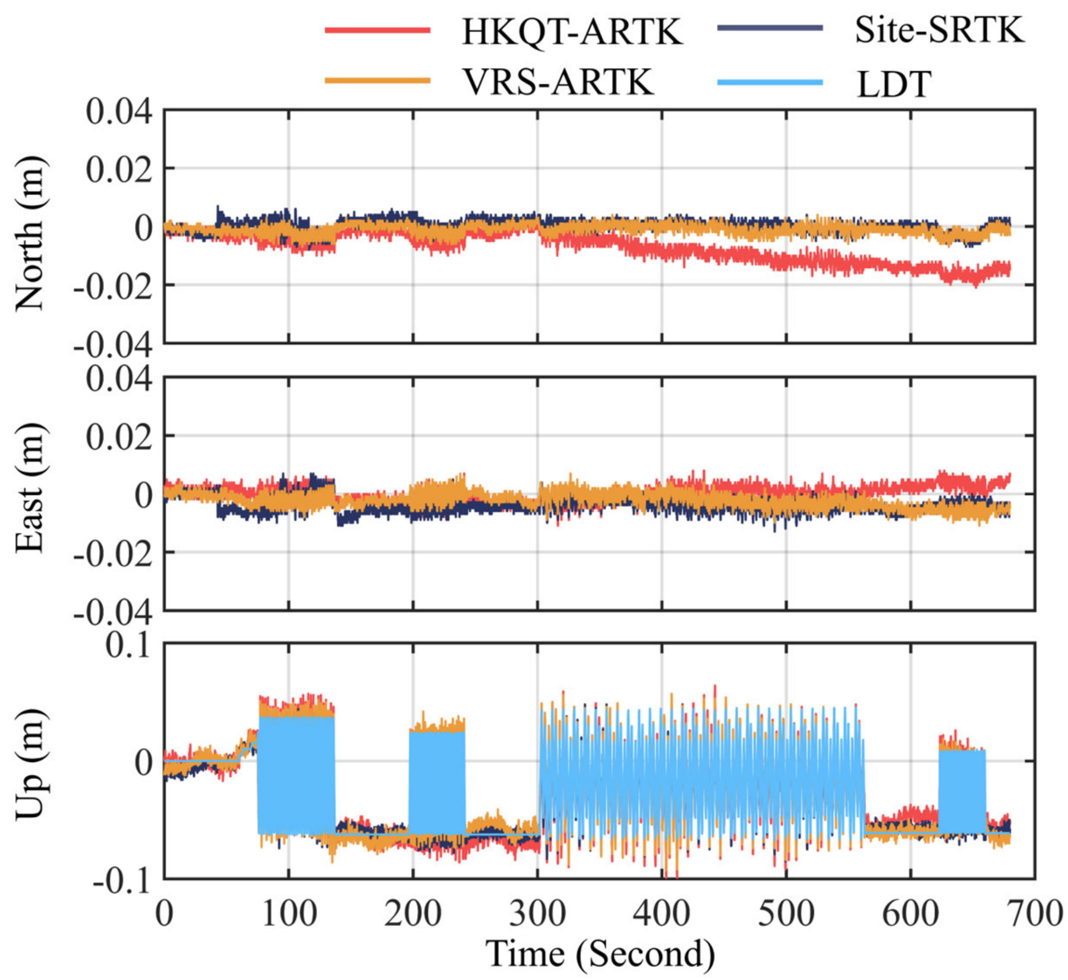
Data Processing:	(1) ARTK using 1 Hz data from a reference station (3.85 km away) and 10 Hz data from the shaking table.
	(2) SRTK using 10 Hz data from a reference station nearby and 10 Hz data from the shaking table.
	(3) ARTK using 1 Hz VRS data and 10 Hz data from the shaking table.

Static Experiments



- VRS – ARTK is 50% better than ARTK using a reference station of 3.8 km away;
- VRS-ARTK achieves similar accuracy as that of RTK with a short baseline (~ 90 m).

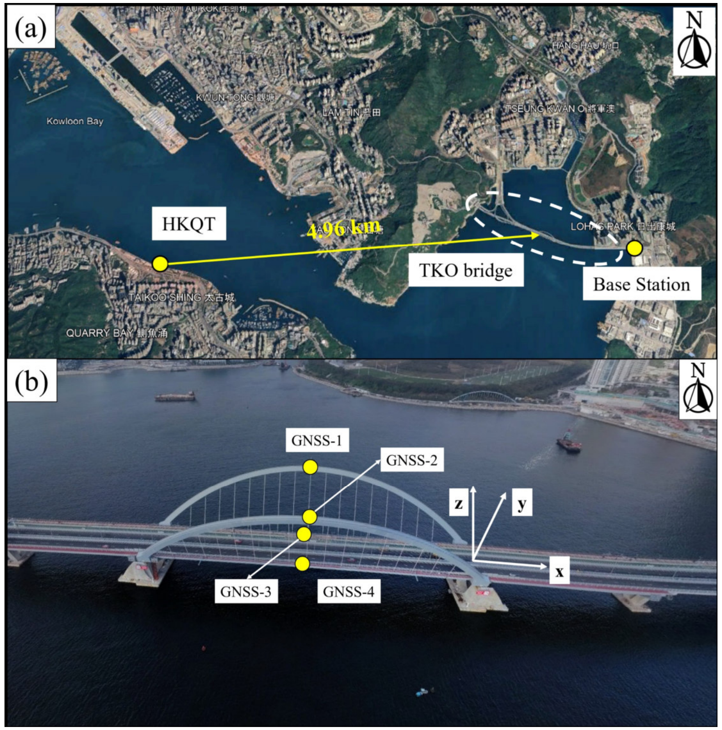
Dynamic Experiments



No. of the motion	RMSE (mm)		
	HKQT-ARTK	SRTK	VRS-ARTK
#1	6.7	5.5	5.9
#2	6.5	5.6	6.0
#3	7.1	5.2	5.7
#4	6.8	5.4	5.6

- VRS and short-baseline RTK achieve best accuracy.

Experiments with Data from Tseung Kwan O (TKO) Bridge

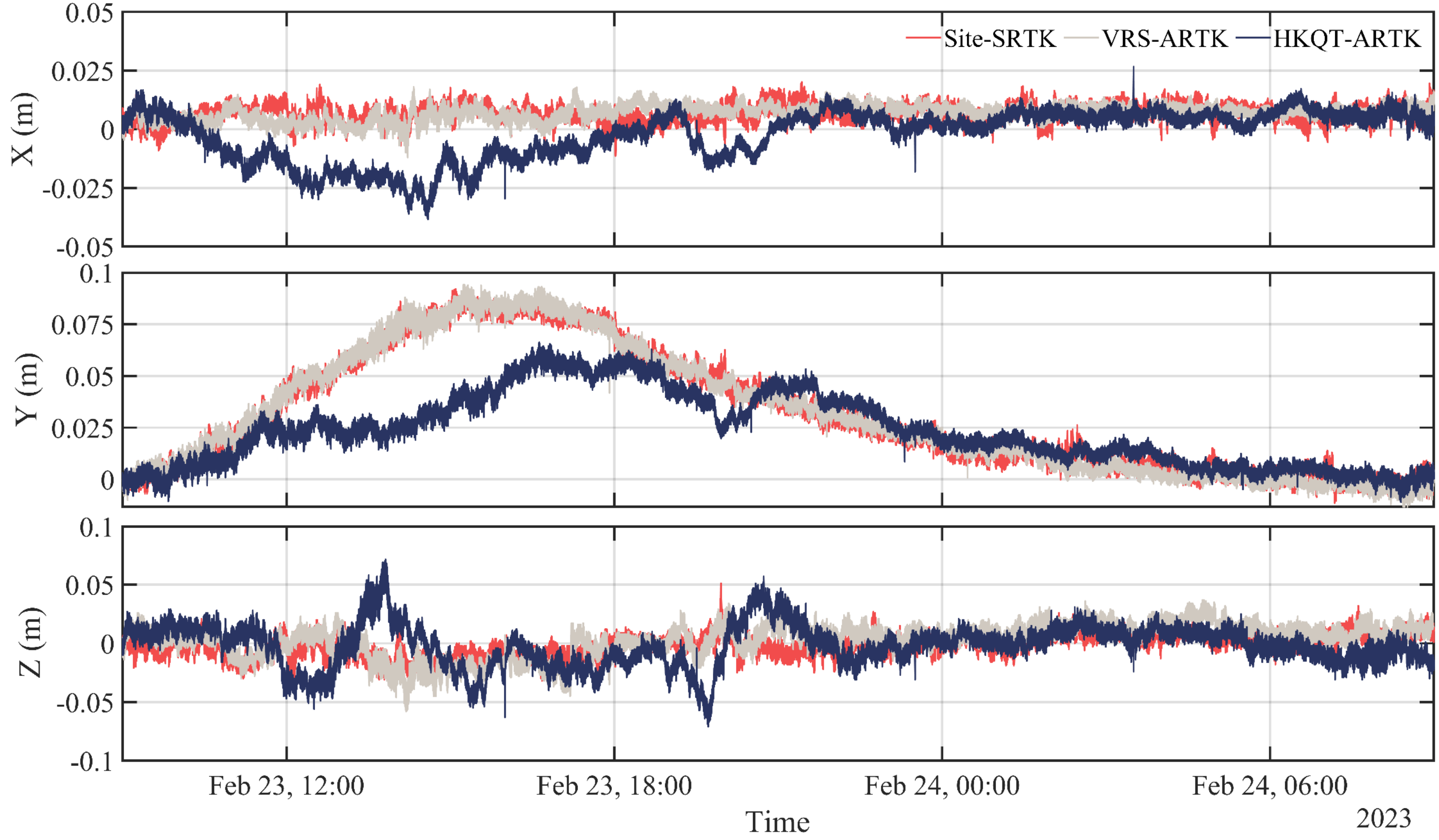


Data Processing Schemes:

(1) ARTK using 1 Hz data from a reference station of 5 km away and 10 Hz data from GNSS-1.

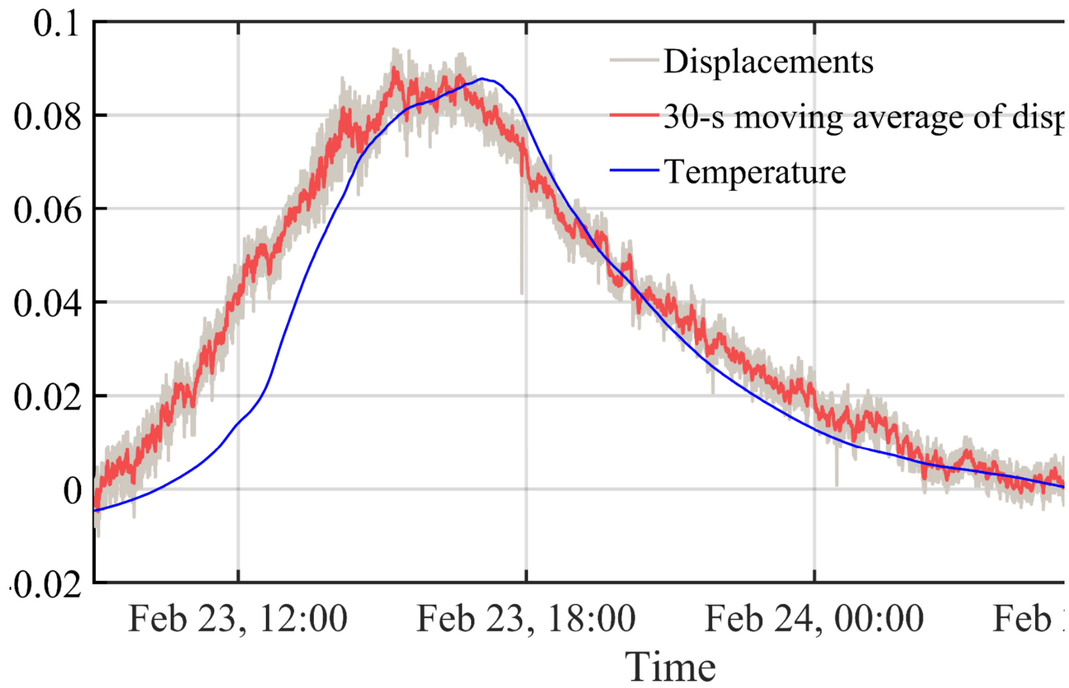
(2) SRTK using 10 Hz data from a local reference station and 10 Hz data from GNSS-1.

(3) ARTK using 1 Hz VRS data and 10 Hz data from GNSS-1.

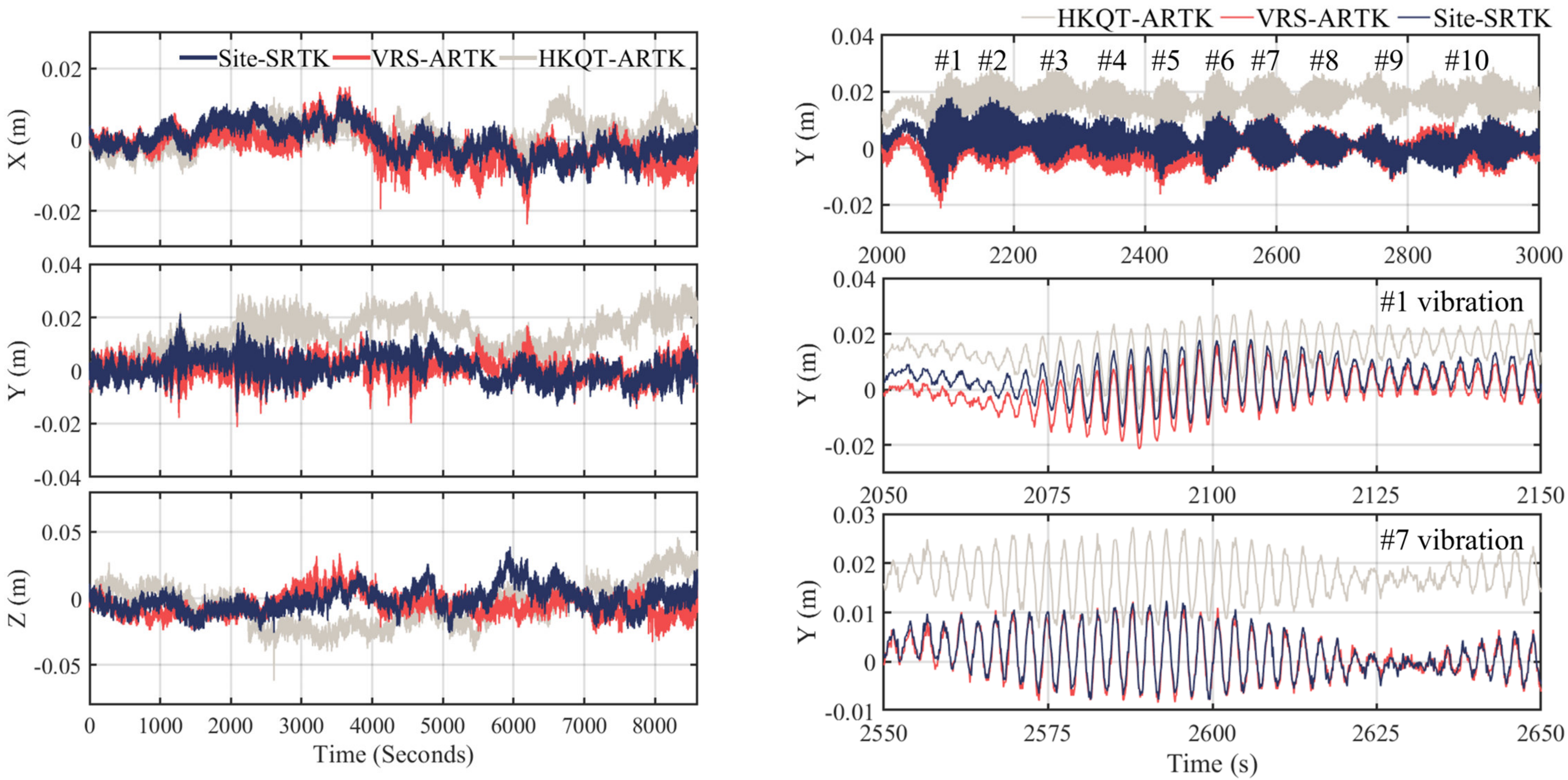

Site-SRTK
VRS-ARTK
HKQT-ARTK
X (m)
0.05
0.025
0
-0.025
-0.05
Y (m)
0.1
0.075
0.05
0.025
0
Z (m)
0.1
0.05
0
-0.05
-0.1
Feb 23, 12:00
Feb 23, 18:00
Feb 24, 00:00
Feb 24, 06:00
2023
Time

Laterial Displacements of TKO Bridge on a Typical Sunny Day

⑩ The transverse displacement and the temperature were strongly correlated with a correlation coefficient of 0.97;



Vibration Analysis



Vibration Analysis

No. of the motion	Frequency (Hz)/amplitude (mm)		
	HKQT-ARTK	Site-SRTK	VRS-ARTK
#1	0.387/6.3	0.387/6.3	0.387/6.3
#2	0.377/5.7	0.377/5.8	0.377/5.7
#3	0.387/5.2	0.387/5.2	0.387/5.3
#4	0.381/4.5	0.380/4.6	0.380/4.5
#5	0.386/5.0	0.386/4.9	0.386/5.0
#6	0.386/5.6	0.386/5.7	0.386/5.6
#7	0.387/5.7	0.387/5.7	0.387/5.8
#8	0.389/3.8	0.389/3.8	0.389/3.9
#9	0.387/4.1	0.387/4.0	0.387/4.0
#10	0.383/3.8	0.383/3.9	0.383/3.8

- All methods detected the vibration frequencies accurately

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Conclusions

- A method is proposed to use low-rate VRS data for high-rate displacement monitoring.
- The accuracy of the method is comparable to that of using a local reference station.
- When using 1 Hz VRS data, up to 100 Hz of displacements can be derived without noticeable loss in the accuracy.
- Performance of the method using other VRS networks may need to be investigated.

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ORIGINAL ARTICLE

High-rate bridge displacement monitoring with low-rate virtual reference station data

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Abstract

We present a new Global Navigation Satellite Systems (GNSS) positioning approach that utilizes low-rate Virtual Reference Station (VRS) data to achieve high-rate displacement monitoring. The method integrates tightly the VRS technology with asynchronous Real-Time Kinematic (RTK) method to overcome the limitation of VRS in high-rate structural health monitoring (SHM) applications. When this approach is used, no local reference station is required so that the efforts and cost of setting up reference stations can be avoided. Experiments with datasets from a controlled shaking platform and a long-span bridge in Hong Kong with both temperature and typhoon excitations have indicated that the proposed approach worked effectively. The results demonstrated that when a baseline exceeded about 3 km, the vertical errors of RTK GNSS positioning could be up to about 15.9 mm (standard deviations), insufficient for most SHM applications. In this case, the proposed method enhanced the accuracy by about 60% to 6.0 mm when using VRS data openly available in Hong Kong. The accuracy achieved was equivalent to that of RTK positioning using a 1.2 km baseline. The shaking platform trial demonstrated that the monitoring station could be up-sampled to 100 Hz without a noticeable loss in accuracy. The proposed method could capture precisely the peak frequencies and amplitudes of vibrations, with errors as low as 0.001 Hz and 0.1 mm. This method broadens the applicability of GNSS positioning in SHM applications.

Keywords Bridge monitoring · High-rate GNSS · Dynamic response · Asynchronous RTK · Virtual reference station

GPS Solutions, (2025), 29(1), 1-18

Download link

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THANK YOU

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The most relevant SDGs related to the presentation and theme of this session

1st relevant SDG

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

2nd relevant SDG

11 SUSTAINABLE CITIES AND COMMUNITIES

3rd relevant SDG

15 LIFE ON LAND

SUSTAINABLE DEVELOPMENT GOALS

International Federation of Surveyors supports the Sustainable Development Goals

STEP 1: SELECT HERE THE THREE MOST RELEVANT SDGs
STEP 2: COPY THE SDG INTO PREVIOUS SLIDE