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Detailed Displacement Analysis of A Box-girder Bridge by Fusion of Multi-orbit X-Band SAR Images

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Abstract

Since the 21st century, the urbanization of human living environment has been accelerated, and a large number of various bridge facilities have emerged. With the increase of operation time and daily load, some bridges have started to experience different degrees of settlement, deformation, cracks and uplift, which seriously affect the safety of daily use of bridges. Therefore, the use of a reliable technology for periodic bridge deformation monitoring is of great importance to prevent public casualties and property damage caused by bridge collapse.

Compared with traditional contact monitoring means (GPS, level, etc.), which have the shortcomings of long monitoring period and are easily affected by the environment, InSAR technology is a non-contact monitoring means, and the monitoring of bridges, tall buildings and other infrastructures by InSAR technology has the characteristics of all-weather detection, high accuracy, low cost, and does not affect bridge operation. High-resolution SAR data can be applied to bridge fine deformation monitoring work with the advantages of higher monitoring point density and sensitivity.

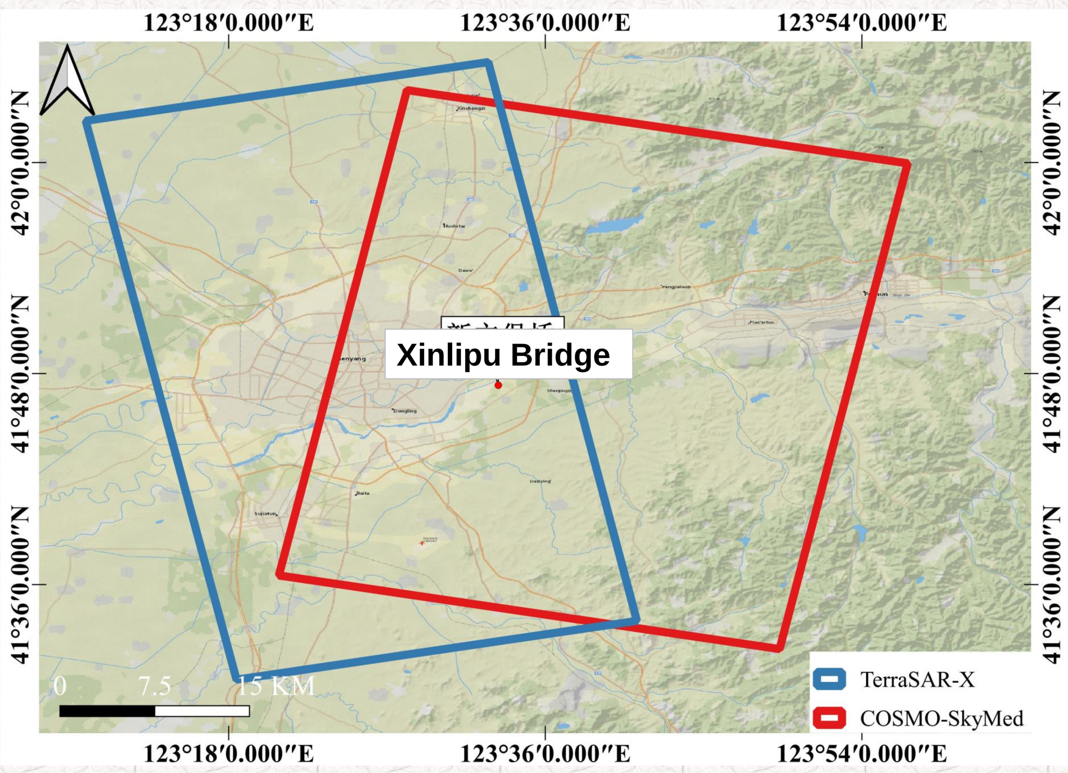
This research is based on a five-span large-span continuous box girder bridge with variable cross-section in Shenyang, Liaoning Province - Xinlipu Bridge over Hun River. The data sources used are 30 images from March 2015 to April 2017 provided by TerraSAR-X satellite and 29 images from August 2015 to June 2017 provided by COSMO-SkyMed satellite, and the data set is processed by SBAS-InSAR technique to obtain the deformation information in the LOS direction of the bridge. The least-squares linear fitting method is applied to extract the temperature influence factor by combining the structural characteristics and material properties of the bridge, and to construct a bridge thermal dilation model to separate the thermal dilation and trend deformation of the bridge. The bridge deformation is the result of the combined effect of periodic thermal dilation and linear trend-type deformation, so separating the thermal dilation from the trend deformation can help us better study the deformation characteristic mechanism of the bridge. Then the multi-source LOS directional thermal dilation is combined with the bridge structure and sensor geometry parameters, based on the natural neighborhood interpolation method, to obtain the bridge along the bridge directional thermal dilation field[1]. Based on the time and space interpolation methods and the principle of singular value decomposition, the LOS trend deformation obtained from the multi-source SAR data is geometrically aligned, interpolated and fused to solve the bridge deformation along the bridge and vertical deformation. Finally, for the visualization of the deformation of the complex structure of the bridge, the deformation points of different structural parts of the bridge are separated and extracted, so that the deformation patterns of different structural parts of the bridge can be better analyzed[2].

The results show that the thermal dilation of continuous box girder bridges is very obvious, and the method of constructing a bridge thermal dilation model based on the least squares method to extract the temperature influence factors of the bridge monitoring points can separate the periodic thermal dilation from the long-term trend deformation of the bridge. Based on various temporal and spatial interpolation methods, the multi-source SAR data fusion method applying the principle of singular value decomposition can obtain accurate bridge vertical and longitudinal deformation information, and the results show that the main span of Xinlibao Bridge has obvious vertical deformation in the middle of the main span, and the secondary span also has vertical and longitudinal displacement. InSAR technology can be used as a conventional deformation monitoring tool to extract and analyze the time series deformation of various bridges, which provides a reliable technology and data support for bridge health inspection.

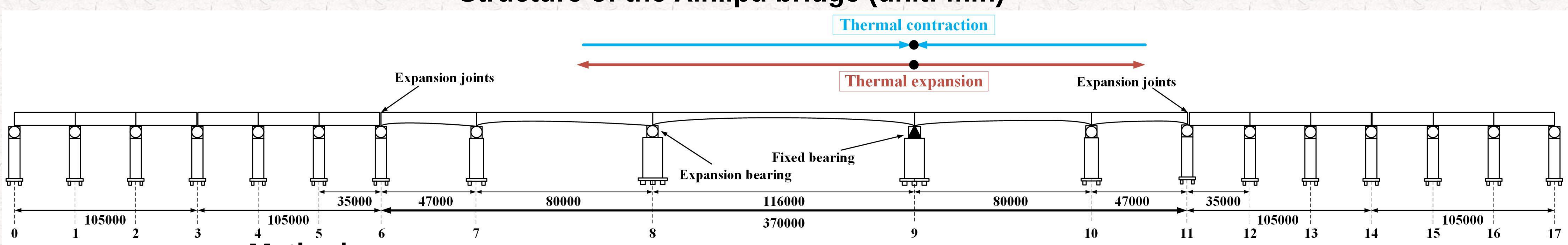
Data processing and results

Study area

30 TerraSAR-X images and 29 COSMO-SkyMed images covering the study area from 2015 to 2017 were selected.



Structure of the Xinlipu bridge (unit: mm)

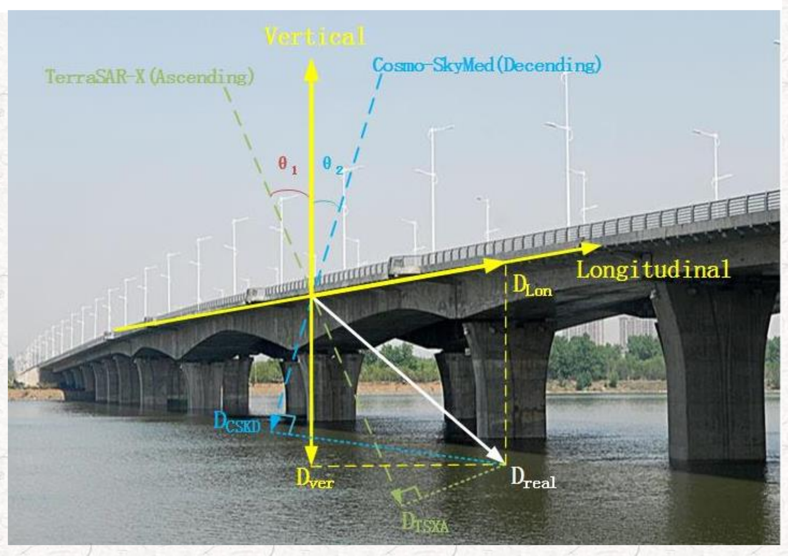


Method

- SBAS method is used to obtain the unwrapping phase of the interference pair.
- Using DEM and singular value estimation method, the phase of vertical stratified atmosphere is removed.
- The residual terrain phase is removed according to the oblique distance, vertical baseline and radar incidence angle.
- Phase to deformation.
- Thermal dilation model of the bridge is established based on least squares adjustment

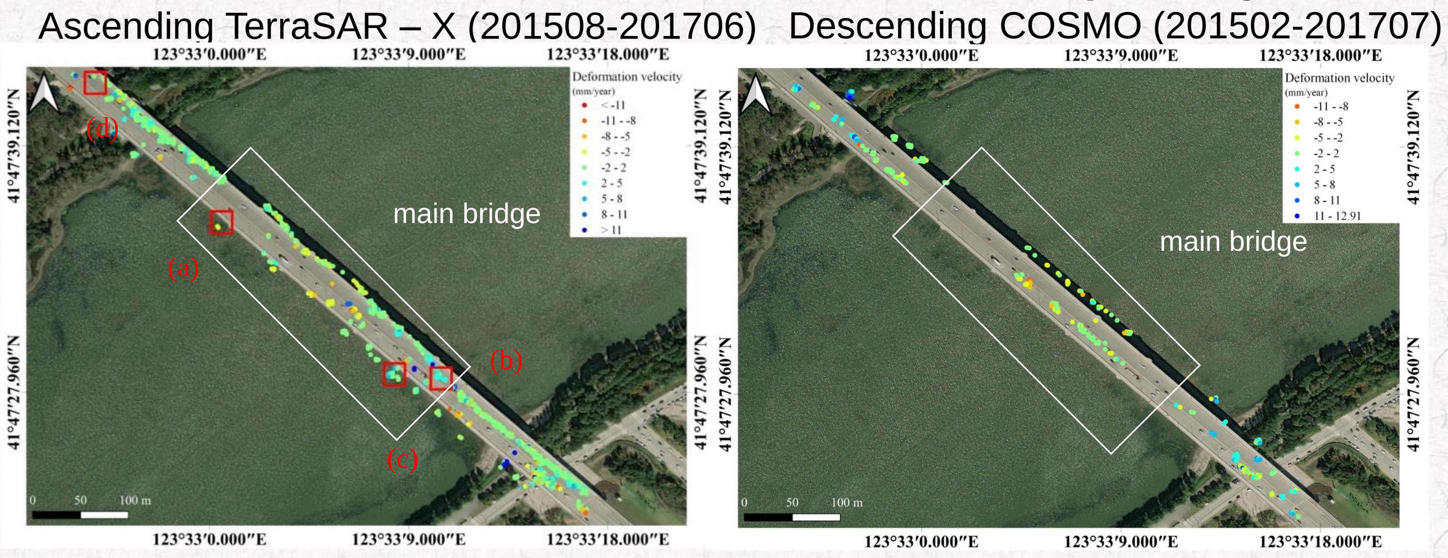
SAR imaging geometry of the Xinlipu bridge

Based on the time and space interpolation methods and the principle of singular value decomposition, the LOS trend deformation obtained from multi-source SAR data is geometrically aligned, interpolated and fused to solve the bridge deformation along the longitudinal and vertical deformation.

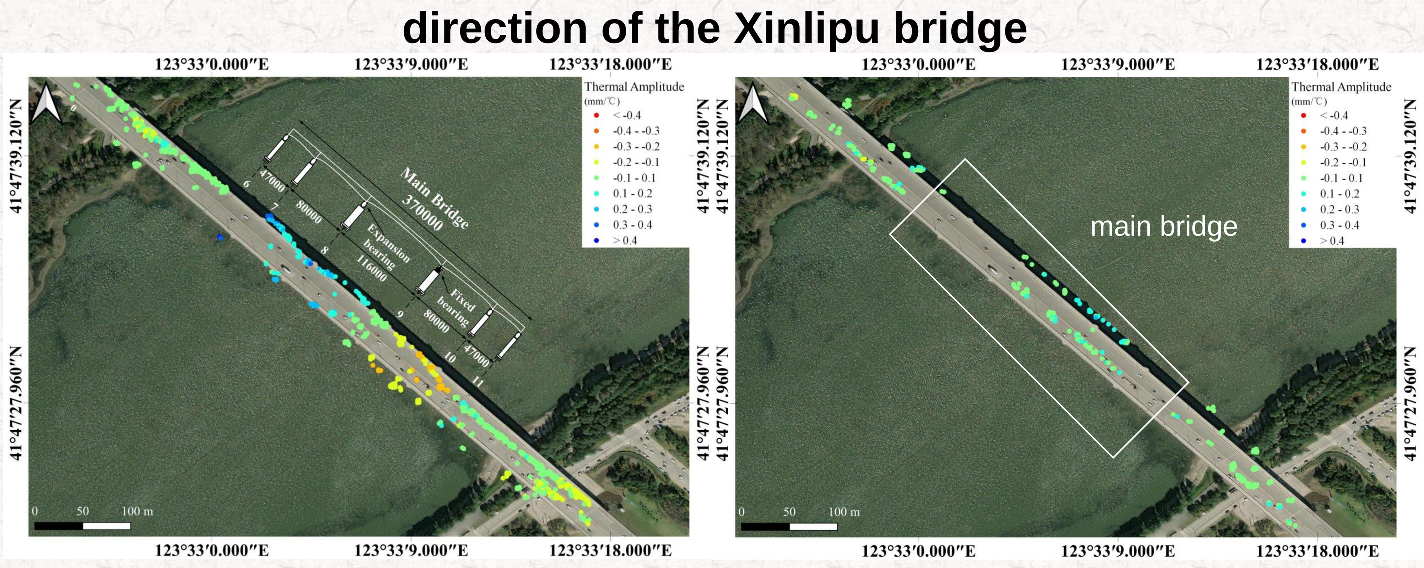


LOS deformation velocities of the Xinlipu bridge

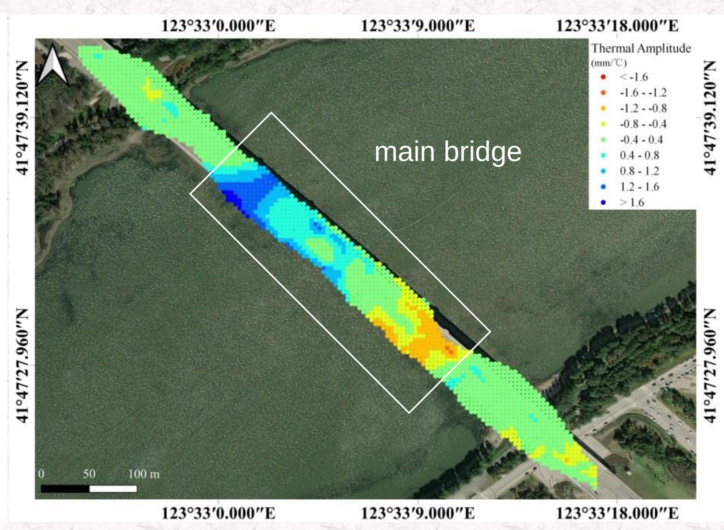
Ascending TerraSAR – X (201508-201706)   Descending COSMO (201502-201707)



Temperature influence factors in LOS direction of the Xinlipu bridge

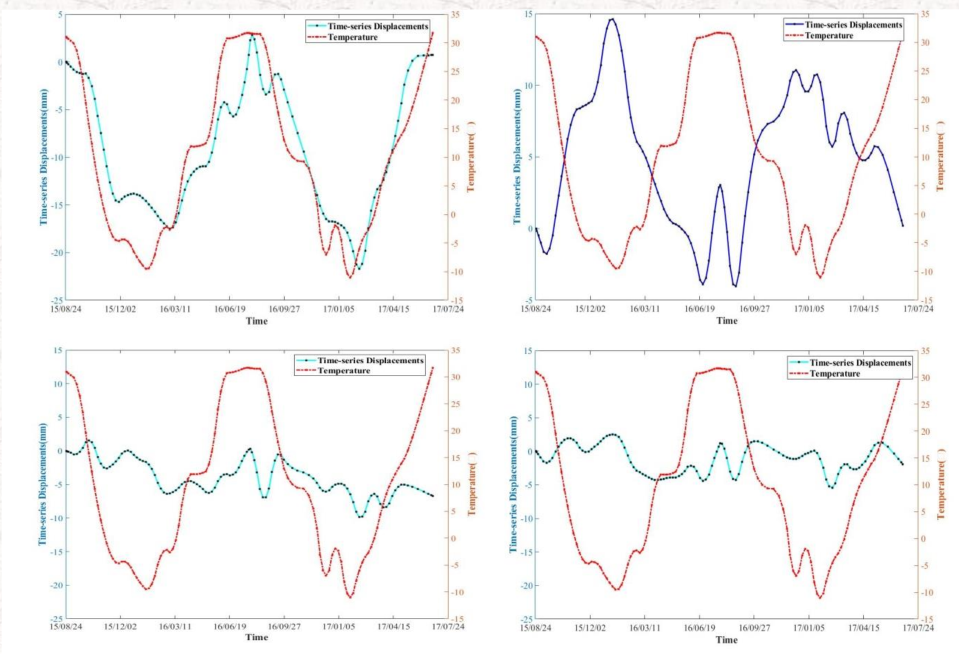


Longitudinal thermal dilation

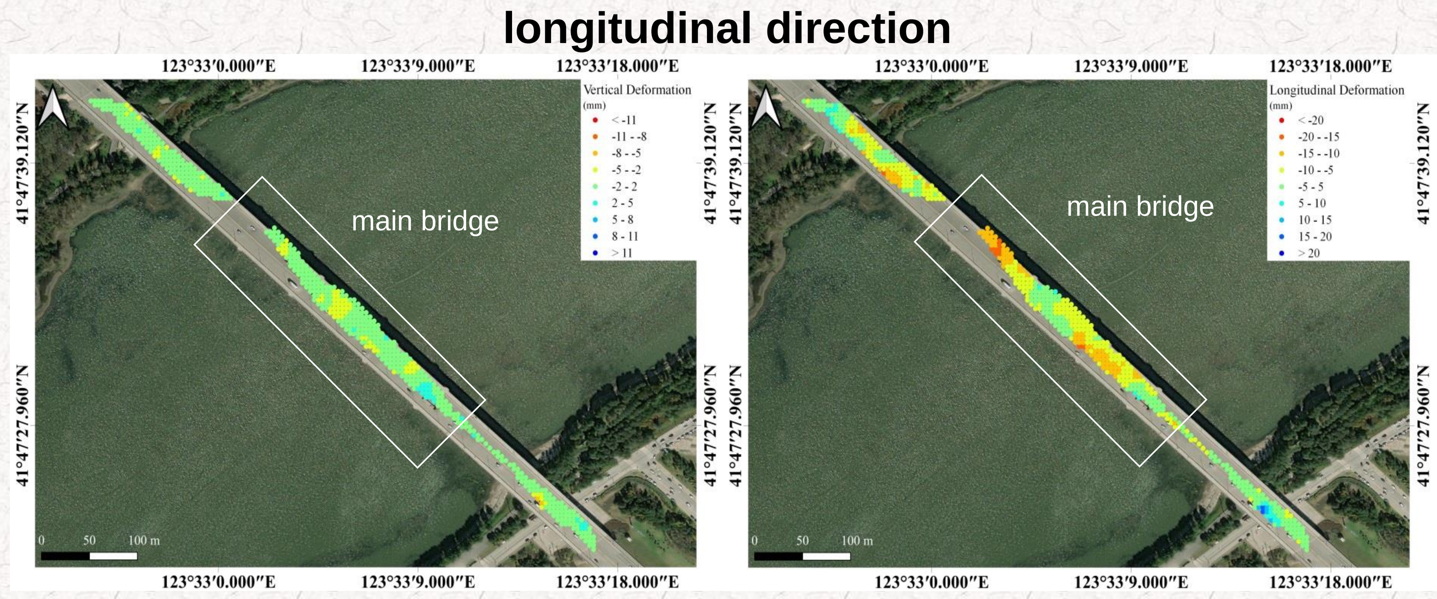


Time-series displacements and temperature change of key points on the Xinlipu bridge

The displacement time series and temperature change of four key points (marked in the displacement velocities map) are plotted. According to their correlation with reference to temperature change, the point targets on the bridge deck can be categorized into four types: (1) points presenting positive correlation; (2) points with negative correlation; (3) point uncorrelated to temperature, including those with linear displacement or no displacement.



Cumulative deformation in vertical and longitudinal direction



Conclusions

- The least squares method is used to extract the temperature influence factors of bridge monitoring points and construct bridge thermal dilation models, which can be used to separate the thermal deformation and structural trend deformation of the bridge.
- Compared with single track time series InSAR data, fusion of multi-orbit (ascending and descending) time-series InSAR data is able to extract detailed deformation of Xinlipu bridge in vertical direction and the longitudinal direction.

References

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[2] Selvakumaran S, Rossi C, Marinoni A, Webb G, Bennetts J, Barton E, Plank S and Middleton C. Combined InSAR and Terrestrial Structural Monitoring of Bridges[J]. IEEE Transactions on Geoscience and Remote Sensing, 2020, 58(10): 7141-7153.

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