Enhancing Resilience of Bridges through Real-time Deformation Monitoring using UWB Technology Enhanced by Machine Learning

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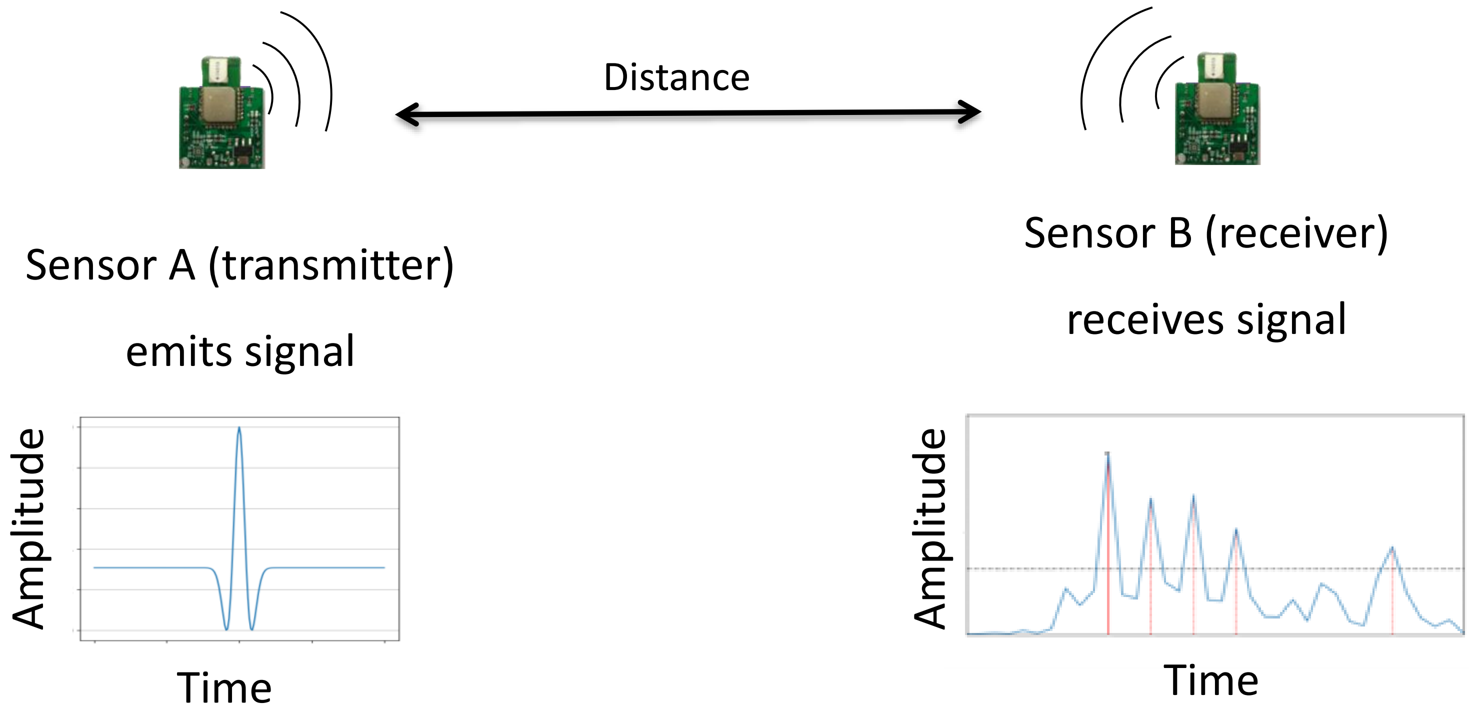
Objectives

- The overarching goal is to develop a new metrology tool for real-time monitoring of bridge deformations with an accuracy as fine as sub-mm order
- Specifically, there are three main objectives:
  - (1) Develop a system that utilizes ultra-wideband (UWB) radio technology to measure distance
  - (2) Utilize a machine learning method to determine bridge deformations from the measured UWB signals
  - (3) Incorporate two error mitigation methods to improve the measurement accuracy

UWB technology can be used to measure distance

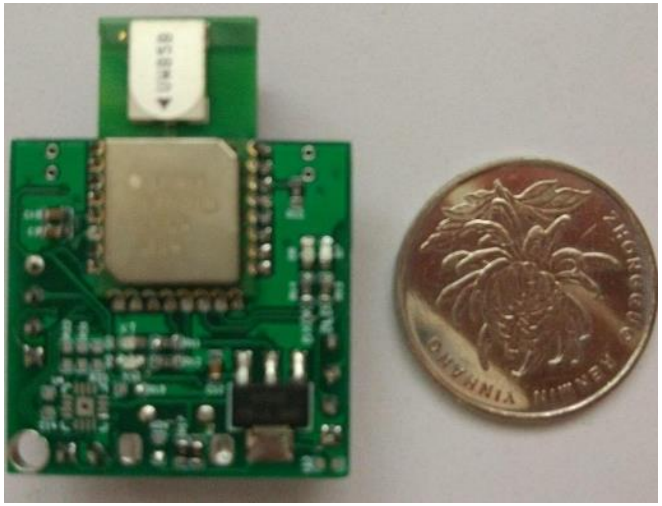
- Two UWB sensors are used: transmitter and receiver



- The distance is determined by measuring the time of flight of the UWB signal between the two sensors

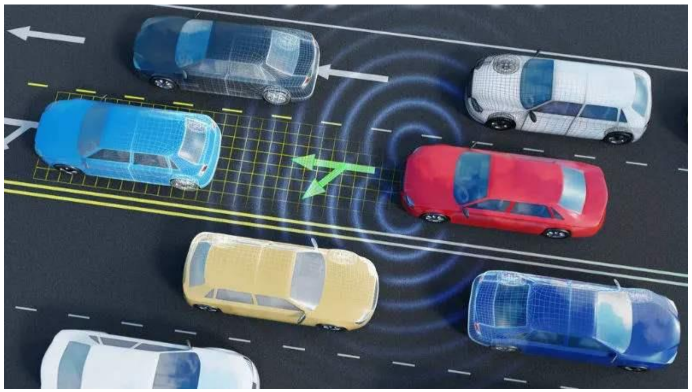
UWB technologies have many advantages

- Low cost: Each UWB sensor can be less than $20
- Low power consumption: 60-80 mAh
- Small: 23mm x 13mm x 2.9mm
- Robust to the weather



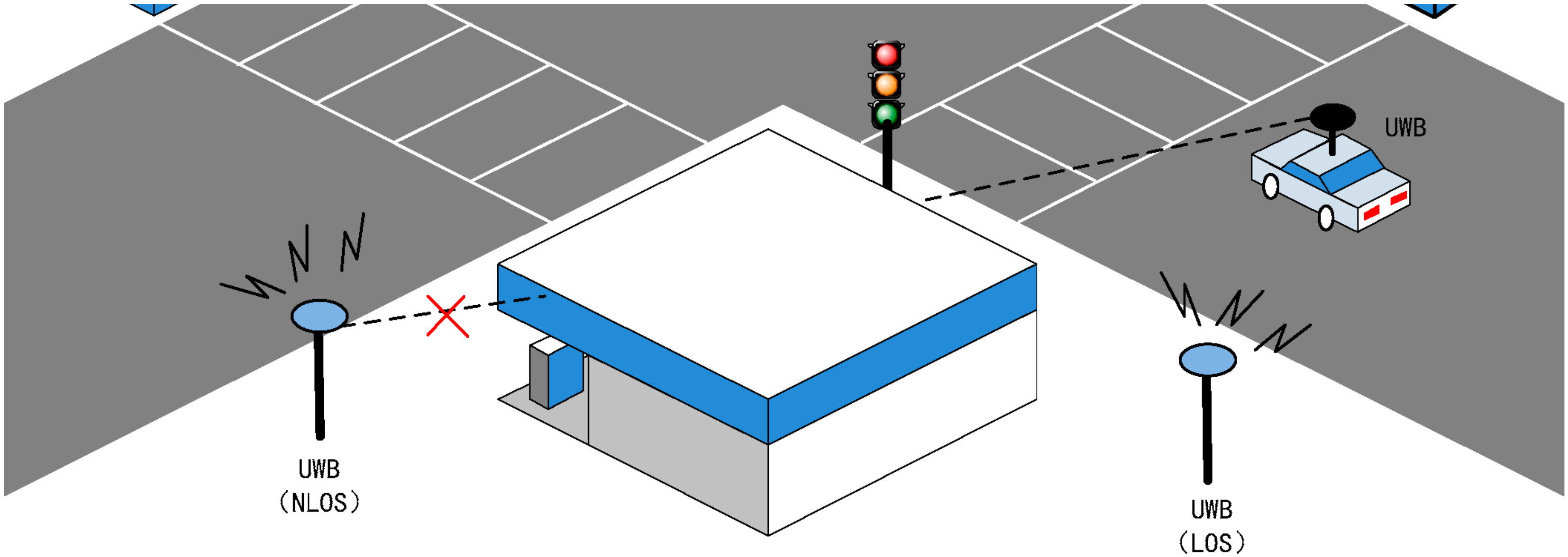
UWB technologies have been used

- Such as autonomous vehicles, robots, and iPhone 11



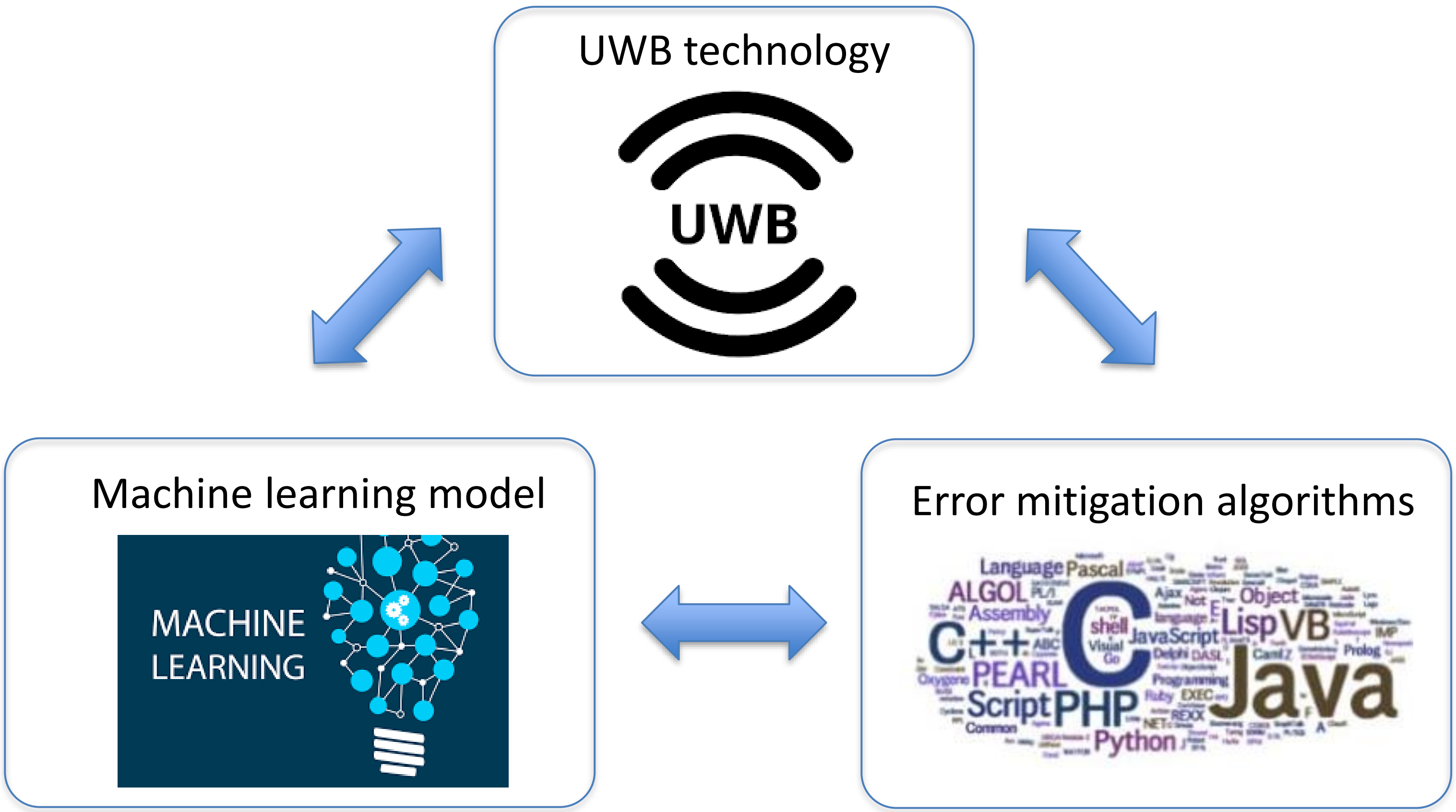
Challenges of UWB method in measuring distance

- The accuracy is about 10-20 cm, which is yet insufficient for measuring the deformations of bridges.
- The low accuracy is associated with multiple reasons, such as time resolution of chips, the obstacles between the transceivers.



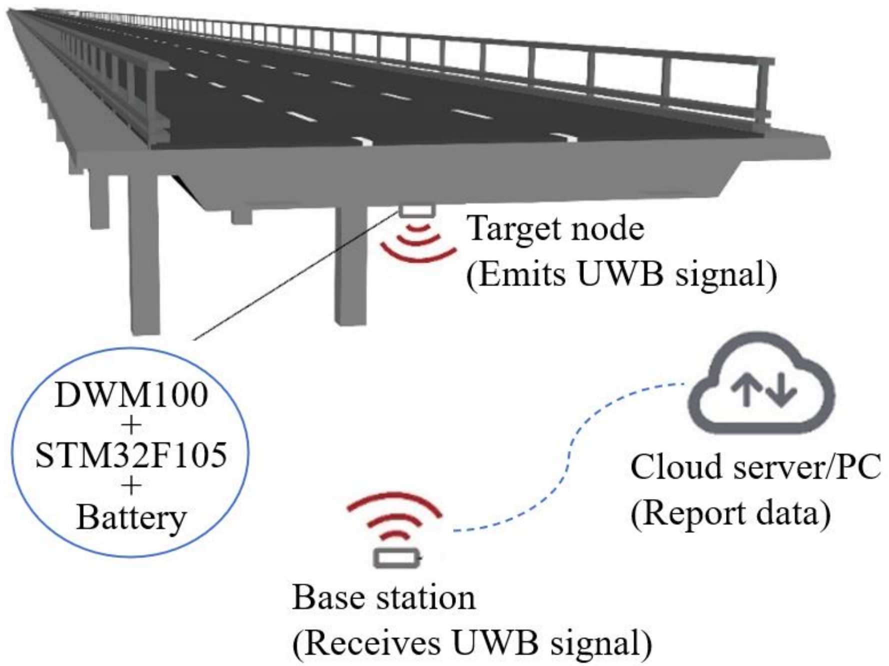
This research improves the measurement accuracy

- Through seamlessly integrating three advanced technologies



The proposed measurement system

- Consists of measurement devices and data analytics module



Raw data from UWB sensors

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Key parameters extraction

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Machine learning model

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Mitigation of errors

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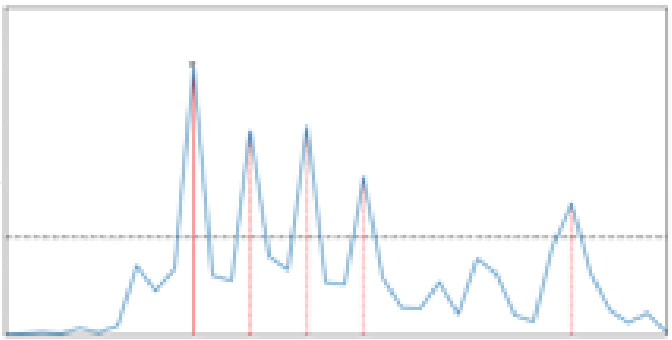
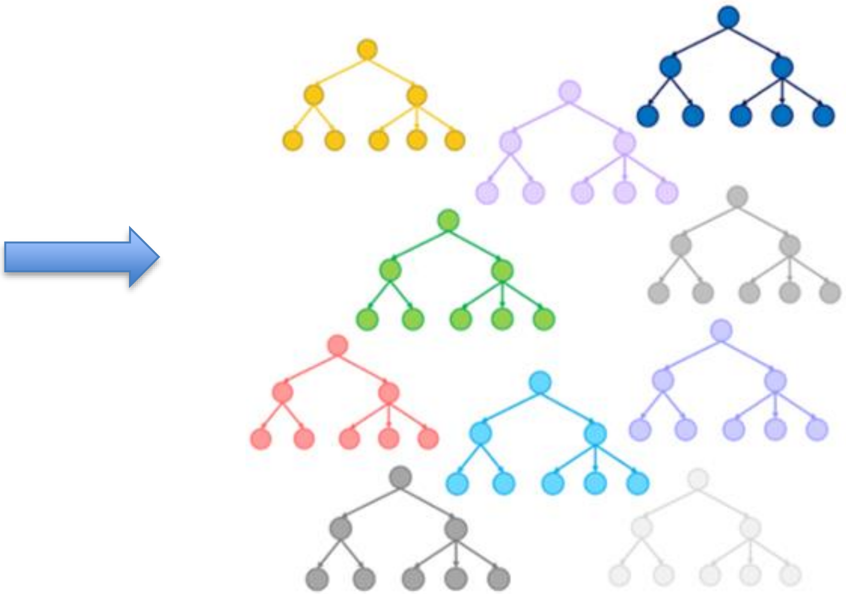
Result

Machine learning model

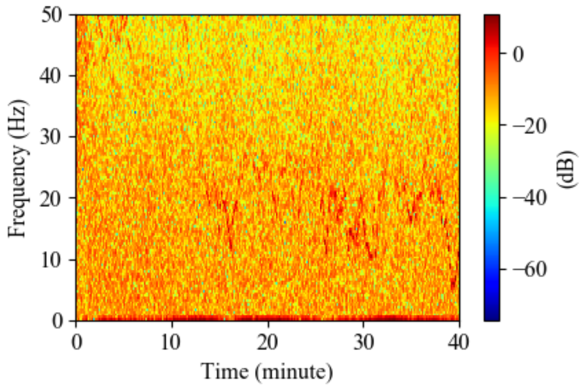
- The XGBoost model based on decision trees was selected because it shows higher accuracy and computational efficiency than the other models, such as random forest, support vector regression, etc.

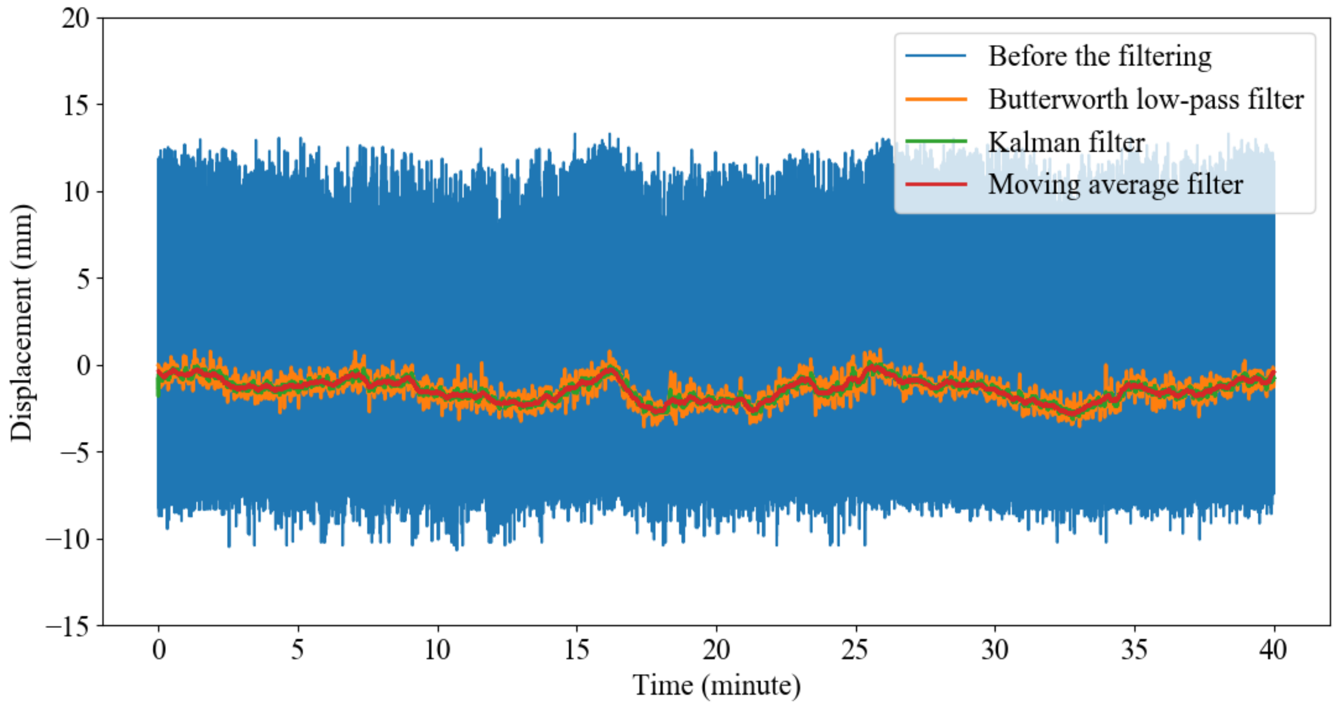




Error mitigation method 1

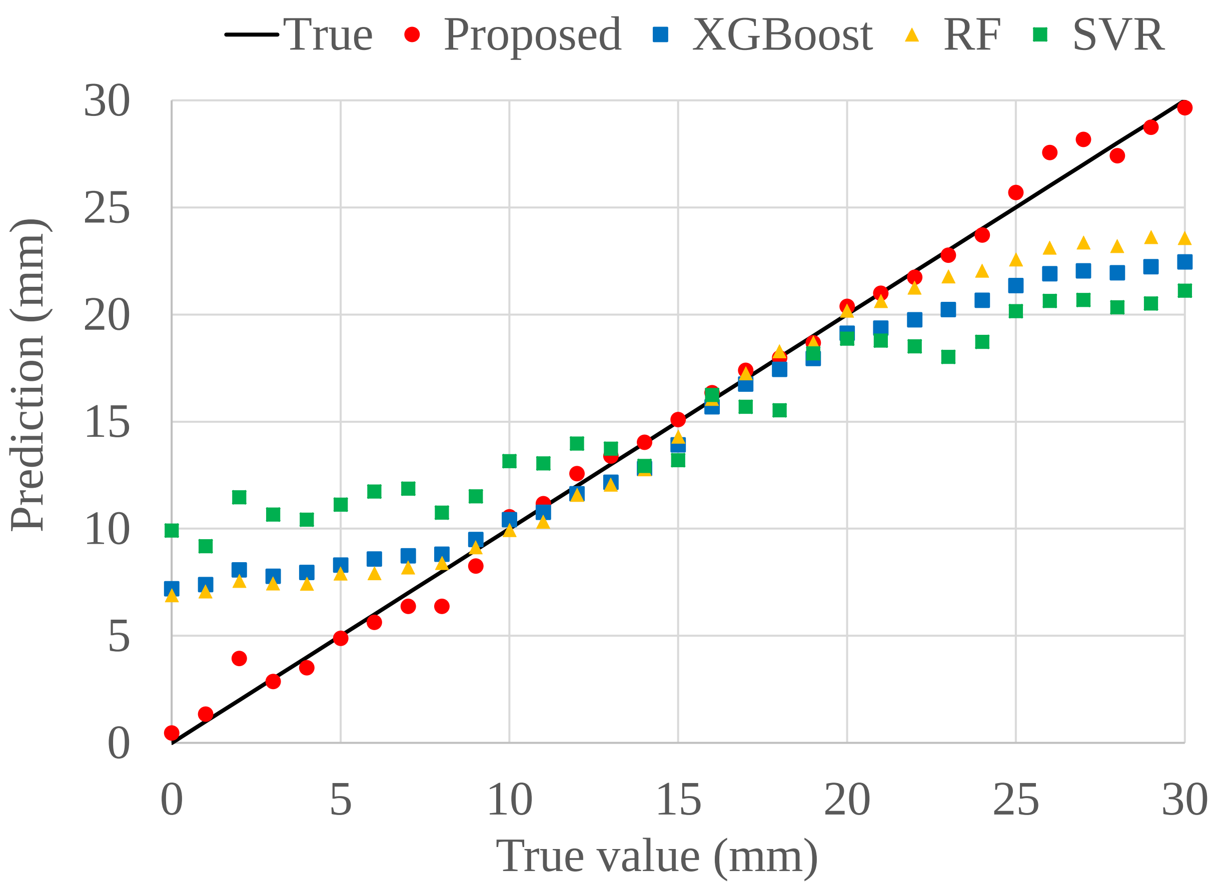
- Uses a low-pass filter to reduce the noise
- Different types of filters were compared
- A moving average filter was selected





Error mitigation method 2

- Uses a polynomial equation to eliminate bias errors due to the decision tree model



Field test for validation

- A concrete highway bridge in operation was tested under trucks in multiple loading cases.

- The whole loading test took 40 minutes. With a sampling frequency of 100 Hz, each UWB sensor collected 240,000 data points.

Instrumentation of the tested bridge

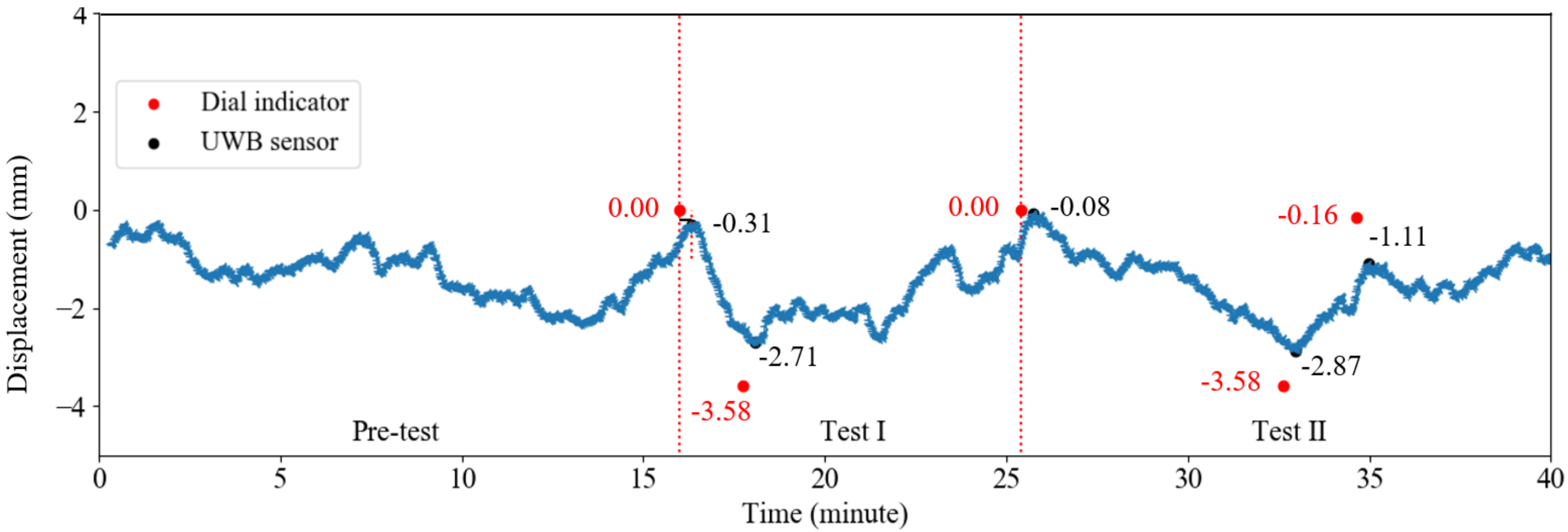
- Dial indicators were used to measure deformations in different cases and evaluate the accuracy of the proposed method.

The target node fixed on the bottom of the bridge

Dial indicator

Representative result

- The maximum error was 0.95 mm.



Conclusions

- The proposed method is effective in monitoring deformations of bridges with a high accuracy, low cost, high efficiency, and reasonable robustness to the weather.
- The proposed algorithm demonstrates desired accuracy and efficiency. The maximum error in this study was 0.95 mm. The measurement frequency was 100 Hz.
- Further research is needed to evaluate the performance of the proposed method for measuring vibrations of bridges under vehicle loading.