

論文の要旨

題目 A Study on Vision-based Distributed Displacement Measurement for Structural Health Monitoring
(構造物ヘルスマモニタリングのためのビジョンベースド変位分布計測の研究)

氏名 Muhammad Zulhaj Aliansyah

Structural health monitoring (SHM) is the process to maintain the safety and reliability of civil structures. SHM is conducted in various methods and approaches depending on the type and construction of the structure. On bridges, the most common practice is periodic manual direct visual inspection and non-destructive sampling by surface tapping. This method is deemed to be impractical due to the limited number of trained inspectors, subjectivity of evaluation, and the location of structural damages at hard-to-reach location in the structure. SHM on bridges could be automated using electronic sensors, ranging from contact sensors such as accelerometer and strain gage, to non-contact sensors such as GPS unit and laser vibrometer by measuring the dynamics movement of the structure from applied loads. Often these methods are still limited due to limited number of measurement points, the nature of localized damage at the early stage, and the requirement of direct proximity to the structural member to be measured for precise measurement resolution.

Convenient SHM method for bridges should be realized to address the vast number of aged bridges currently still in service. Vision-based SHM works by capturing dynamic displacement of measurement points located on the bridge from a distance. Vision-based method takes advantage from development of video camera system with high frame rate and pixel density. This promises implementation scalable to various sizes and construction types of bridges, reliable accuracy of the measured displacement, and ability to detect structural changes from vibration characteristics. Nonetheless, common implementation vision-based SHM is limited due to several constraints of which this study tries to address:

- placement of the camera should be optimal to cover multiple measurement points representative of structural displacement at multiple vibration directions without occlusion,
- limited depth of field of the lens should be addressed by allowing certain amount of expected focal blur of the observed markers and setting the aperture narrow to allow as much depth of field to cover the entire bridge span,
- low measurement resolution in spatial and temporal domain is to be addressed with usage of telephoto lens and high-speed camera system,
- low incident light from the long distance between markers and camera and the reluctance to rely on changing natural sunlight is to be addressed using retroreflective makers and collimated lighting setup,
- robustness of implementation from environmental noises in the measurement and compensation of optical distortions due to lens orientation and varying measurement distances,
- convenience of deployment without traffic closure on the bridge and the ability to measure structural response from driving-by vehicles.

The proposed system in this study includes high-speed camera system to extrapolate the markers displacement from the captured motion in the camera. The measured displacement has high conformity to the actual displacement (~96% accuracy from 12 m measurement distance) at sampling rate beyond the expected natural vibration major frequency of bridge structures. With proper scaling factor, the measurement accuracy was then expanded for application on longer distance measurement in an actual bridge.

Subsequent analyses are then carried out on the obtained markers' dynamics displacement signal to infer meaningful metrics regarding the structural integrity of the bridge. A model bridge underwent dynamics measurement under resembling modal testing of a structure from single excitation. Several algorithms for the analyses of dynamics displacement signal are:

- Fast Fourier Transform (FFT) to evaluate the vibration frequencies of the structure,
- Estimation of the corresponding damping ratio using half-power method for each vibration frequency peaks,
- SSI-CPAST modal analysis to extract the resonant frequencies and the corresponding modes shapes,
- Differential displacement to estimate the static component of the induced displacement.

Later, FFT and differential displacement analyses were carried out on an actual bridge, owing to the random, complex, and uncontrolled nature of excitation force from driving-by traffic.

Various damages on a bridge can then be inferred from the dynamics measurement obtained from the vision system, such as overloading condition reflected in peak displacement exceeding the design value; plastic deformation of fatigued members can be inferred from cumulative residual displacement; the decrease of particular natural vibration frequency in specific direction implying reduction of structural stiffness and failure of damping devices; also localized damage from crack or loose connection can be estimated from the slight change in the modal shape.

The proposed vision-based distributed displacement measurement method has been demonstrated to be feasible for actual field application of structural health monitoring, coupled with traffic counting system to identify structural response of the bridge from the passing vehicles. Both single side and dual side configuration is possible to simultaneously capture lateral and vertical displacement of structural members simultaneously at multiple points installed at either chord of the bridge. The system was able to infer shifts in natural vibration frequencies and mode shape reflecting structural changes in a bridge. The implementation with video camera and telephoto lens resulted in acceptable measurement spatial resolution for medium span bridges.