Investigation of Advanced Techniques in Structural Health Monitoring

Xianqiang Wang
Jilin University, China
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The research supported by the SRA program of the Tokyo Foundation gives the opportunity to investigate the advanced techniques in the field of Structural Health Monitoring (SHM) and will be helpful to enrich and improve my doctoral work.

Structural damages seriously threaten the people's life and property safety, which also affect the sustainable development of economy and society. In order to guarantee the structural operation safety, SHM systems have been rapidly developed and widely used in the large-scale buildings and long-span bridges. Among them, Vibration-based Damage Detection (VBDD) is the most important part to provide the early warning and find the potential risk based on the change of dynamic characteristics which are sensitive to structural damage. However, environmental factors may also cause the changes of these dynamic characteristics to result in a false alarm. In order to avoid the false damage detection results, the changes of dynamic characteristics caused by environmental variation must be understood, quantified and discriminated from those caused by structural damage.

In order to overcome the difficulties in the SHM and solve the problems faced in the VBDD caused by environmental factors, especially temperature, the advanced techniques should be studied and proposed. Therefore, the main aspect of my PhD research is focused on proposing an effective damage identification strategy which can discriminate environmental effect. The tentative title of my doctoral dissertation is: *Modal Parameter Identification and Damage Detection of Bridge Structure under the Influence of Environmental Factors*. It will have a contribution to the development of effectively detecting the damage in bridges by eliminating the temperature effect.

The topic of my proposed research project was: *Field and Interview Investigation of Advanced Techniques for Structural Health Monitoring and Damage Identification of Bridges*. For this research abroad, SRA award made a significant contribution and provided a great help. Most of my research abroad was spent on conducting investigation in advanced techniques for SHM at Korea Advanced Institute of Science & Technology (KAIST). During the research period, I visited Civil & Environmental Engineering at KAIST, one of the well-known institutions for SHM in Korea, for 16 days. Prof. Sohn is the famous scholar in this field of SHM. The advanced methods about damage detection of bridges have been proposed by him, and corresponding findings have received the international recognition. Through interview and discussion with Prof. Sohn and his PhDs, I have obtained the important material to enrich and expand the original research about doctoral dissertation. In addition to discussion, I also visited Smart Structures and Systems (SSS) Laboratory and on-going SHM projects in the charge of Prof. Sohn. Through the field investigation, applied advanced theories, methods, technologies provided the first-hand data and new ideas for my future research.

In order to achieve the structural damage detection under the influence of temperature, two approaches have been proposed. One approach is to measure environmental parameters as well as the vibration features over a wide range of these varying conditions to characterize the normal condition. Data normalization is applied to separate changes caused by environmental variations from structural damage. Several dada normalization methods including simple linear model, multi-linear model, back propagation neural network model and support vector machine model have been researched for these cases. On the other hand, it is difficult to measure environmental parameters. Furthermore, if structural damage produces a change of dynamic features that is 'orthogonal' and 'uncorrelated' to the change caused by environmental variability, it may be possible to detect the damage without a measure of the environmental variability [1]. For the latter case, the advanced techniques proposed by Prof. Sohn at KAIST make it possible to explore the damage detection indicators which are sensitive to damage but insensitive to temperature.

During the investigation at KAIST, the advanced experimental equipments and techniques shown to me extended my horizons. The new techniques based on impedance, nonlinear ultrasonic modulation, laser nonlinear wave modulation and laser thermography provides creative solution to detect the fatigue cracks under the influence of temperature. The impedance based damage detection technique is recognized as a promising tool for SHM as its sensitive to incipient damage. Therefore, the structural damage can be detected by the monitored change of the impedance signal [2]. For avoiding the temperature interference, a new data normalization based on the Kernel principle component analysis (KPCA) is proposed to minimize false-alarms due to variations of temperature. Nonlinear ultrasonic modulation components (sidebands) are produced when low-frequency (LF) and high-frequency (HF) inputs are applied to a structure with nonlinear damage [3]. They appear at the sum and difference frequencies of the generation frequencies and are 'orthogonal' to the change caused by temperature. Another interest is to combine the nonlinear ultrasonic wave modulation technique with noncontact laser scanning [4]. The laser based nonlinear wave modulation technique can be used to detect fatigue cracks by comparing the number of frequency peaks in the frequency response function. In particular, laser thermography is attractive for surface crack detection [5]. Laser thermography utilizes IR camera to capture the propagation of the laser-induced heat and achieves the visual detection for surface crack. These techniques all posses the ability to detect the structural damage, especially for fatigue cracks, without the influence of temperature variation.

There are so many advantages in these advanced techniques, which will extensively affect the development of SHM. The damage detection techniques with the features of noncontact, reference-free and insensitive to temperature will lead the development of SHM in the future decades. Firstly, these advanced techniques can achieve high spatial resolution and improve damage sensitivity; Secondly, they can reduce the cost for the installation of sensors; Thirdly, damage detection base on these advanced techniques is reference-free without relying on history information, which can avoid false alarms due to temperature variation; Finally, they can be used to detect the damage in rotating or moving objects, and applied in high temperature and radioactive conditions. In the future, it is envisioned that these techniques be integrated with unmanned aerial vehicles or inspection robot agents to provide fully automated inspection for large-scale and distributed infrastructure [6].

The investigation at Civil & Environmental Engineering, KAIST is extremely helpful for my PhD dissertation. It not only provided me the advanced techniques in the field of SHM, but also enables me to produce creative ideas. The advanced theories and methods obtained in investigation are very important to enrich and expand my dissertation. The understanding about development orientation of SHM is more comprehensive after numerous discussions with experts and scholars during my SRA period. In addition, through SRA, valuable connections with famous scholars at KAIST have been established, which will be helpful for my future research projects.

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