Summary of the MSc Thesis

Thesis title

A Damage Identification Approach for Spatial Grid Structures Using LAL-AdaBoost

Project objectives and goals

The spatial structures, represented by the National Stadium (the Bird Nest) and Tianjin National Convention and Exhibition Center, play an important part of modern architectures. These buildings not only have their own functionality, but also have great economic, cultural and political significance. Structural health monitoring (SHM) technology is an important means to ensure the structural safety of building structures during the construction and operation stages. Due to the characteristics of spatial structures, SHM technology for such structures is usually unapplicable in various aspects:

1) ***Data processing***: abnormalities in data can lead to serious analytical error in later assessment, while previous research mainly focused on image-based data anomaly detection which can hardly be applied to spatial structures because the data amount can be extremely massive.
2) ***Damage features extraction***: modal parameters-based features indexes are often difficult to obtain; those existed damage features are not sensitive to damage of spatial structures due to its complexity.
3) ***Defect identification algorithms***: multiple damage scenarios are to be considered for SHM of spatial structures, which generally requires tedious training process; additionally, over-fitting problems can be quite common when it comes to supervised machine learning algorithms.

To conclude, it is of great practical significance to carry out SHM research on spatial structures. Therefore, the author proposed a damage identification framework especially for spatial structures based on a novel LAL-AdaBoost algorithm in this thesis, aiming at identifying damages of spatial structures using both in-situ and simulated dynamic responses, achieving higher calculation accuracy and efficiency.

Description of method and results

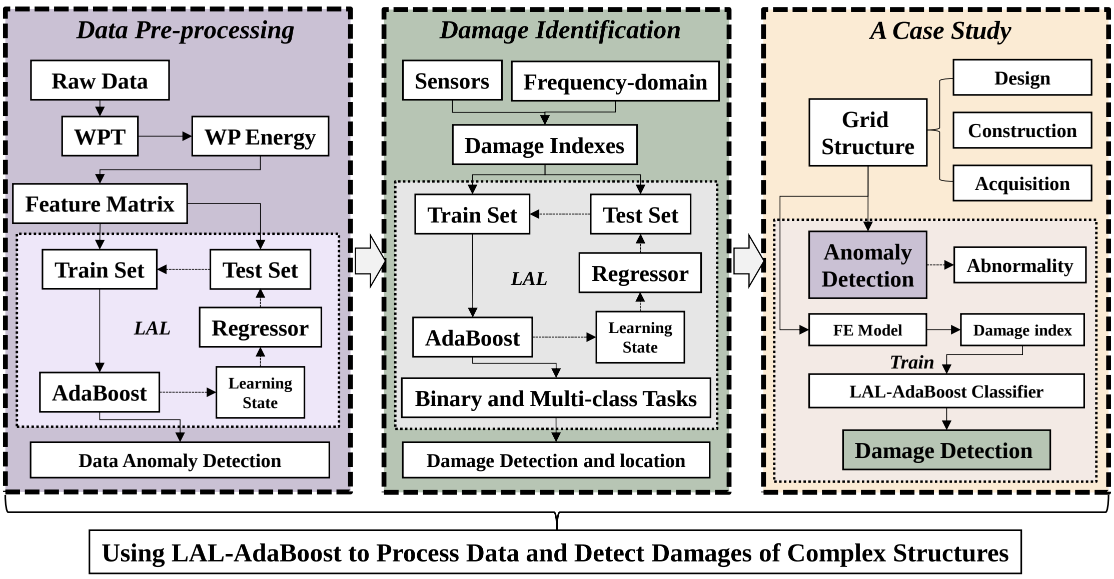


FIGURE 1. Roadmap of the thesis.

In this thesis, the LAL-AdaBoost algorithm was proposed and utilized in SHM of spatial grid structures. Specifically, by constructing Learning Active Learning (LAL) query process using AdaBoost Classifier as the base estimator, the LAL-

AdaBoost algorithm was utilized in data anomaly detection and damage identification and comparative studies showed that it has better performance on SHM of spatial structures. Additionally, a novel damage index was proposed participating as the input feature vector of LAL-AdaBoost. The framework of the damage identification procedures is shown in **FIGURE 1** below.

The LAL-AdaBoost algorithm (**FIGURE 2**) has the advantage of significantly saving the costly manual labeling work compared with other traditional machine learning and deep learning algorithms, via updating query strategy based on the estimated error reduction values. Furthermore, by predicting the potential error reduction learned from the learning states parameters, LAL-AdaBoost manages to achieve better results on minority classes thus to prevent biased classification results.

An experimental study of a grid structure (**FIGURE 3**) was carried out in this thesis to verify the feasibility of LAL-AdaBoost. The grid structure with the size of 5.4m×5.4m, containing nine orthogonal square pyramids with 8 columns made of I-beams. The size of each pyramid of the grid is 1.8m×1.8m×0.5m. A total of 15 acceleration sensors measuring points are placed on the upper and lower nodes of the grid structure, with the excitation of Gaussian white noise. The experimental acquisition scheme is to carry out 3 tests every hour, each time for 2 min, with the sampling frequency of 500Hz. The length of data collected in each test is 60,000, and the experiment lasted 14 days.

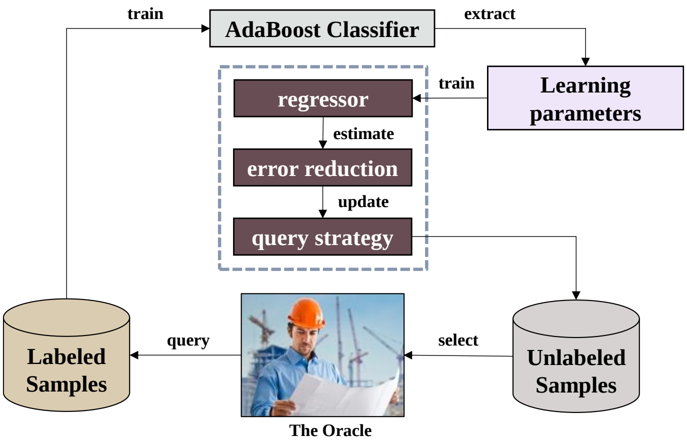


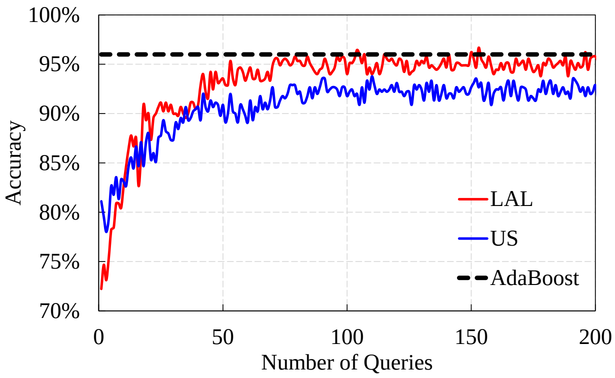
FIGURE 2. The LAL-AdaBoost algorithm.

FIGURE 3. The experimental spatial grid structure.

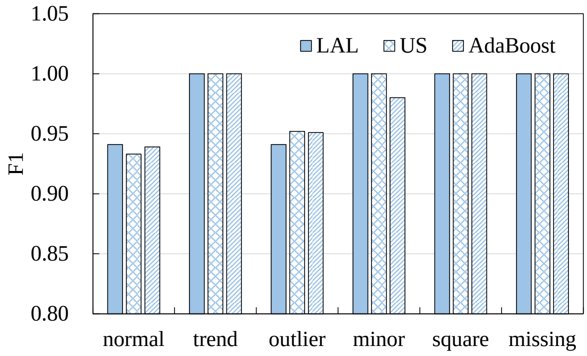
The results of the thesis can be concluded as follows:

1) ***Data anomaly detection of synthetic data***: 5 data anomaly patterns were considered and constructed using the in-situ datasets to verify the performance of the proposed LAL-AdaBoost. Comparison study was also carried out using both LAL and Uncertainty Sampling (US) active learning algorithms. It can be observed from the results (**FIGURE 4**) that LAL-AdaBoost achieved excellent F1 scores and overall accuracies, compared with US-AdaBoost. By only querying 10% of all samples, LAL-AdaBoost managed to achieve better results on minority classes (outlier and minor, e.g.) to avoid biased classification.
2) ***Damage identification of the experimental grid structure***: a novel damage index was proposed using frequency-domain analysis and considering the spatial layout of the acceleration sensors. The results have shown that LAL-AdaBoost has the characteristics of fast convergence and high accuracy (**FIGURE 6**). In total of 4 different damage scenarios were considered in this thesis, and LAL-AdaBoost outperformed US-AdaBoost in each case, proving its advantage of classifying complex tasks with high recall and precision values. Anti-noise experiments were also carried out to further test the performance of LAL-AdaBoost, the results of which were shown in **FIGURE 7**.
3) ***Further verification study of Tianjin No.1 Middle School Stadium***: a finite element model of the Tianjin No.1 Middle School Stadium (grid structure) was constructed to verify the feasibility of LAL-AdaBoost to perform on the damage identification of complex real structures. The author utilized principal component analysis (PCA)

method to pre-process the data features to obtain better results. The LAL-AdaBoost algorithm achieved accuracy of 97% and 93% on damage detection and location tasks, respectively.



(a)



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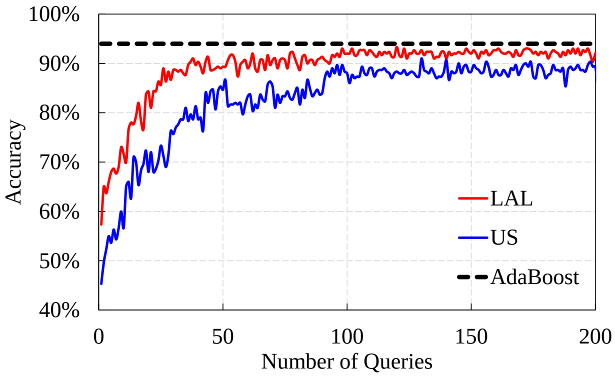

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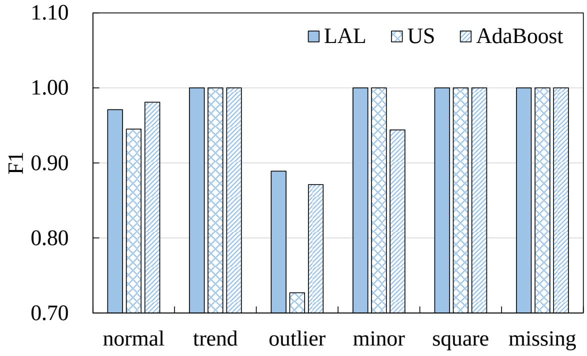

(d)

FIGURE 4. The results of data anomaly detection. (a & b: balanced set; c & d: imbalanced set.)

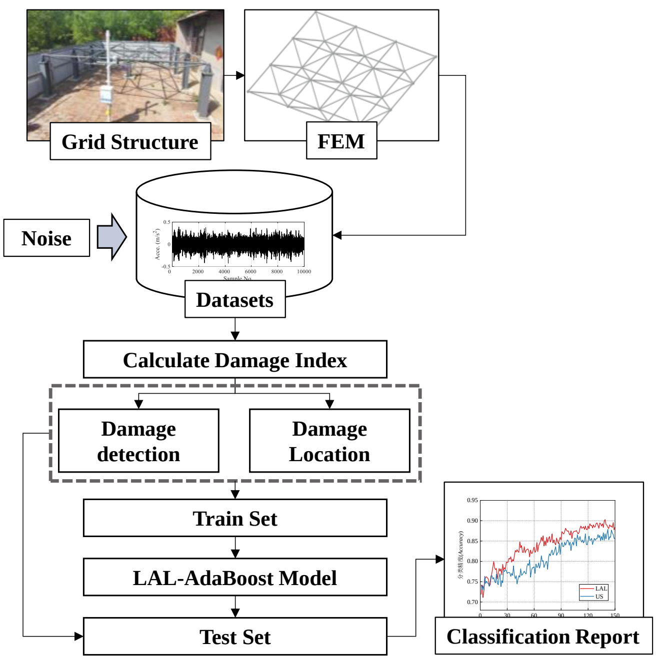

FIGURE 5. Damage identification procedures.

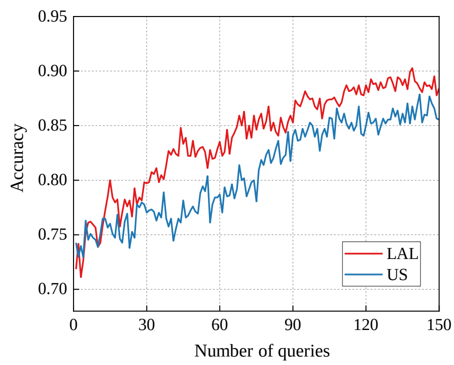

FIGURE 6. Classification curves of LAL and US.

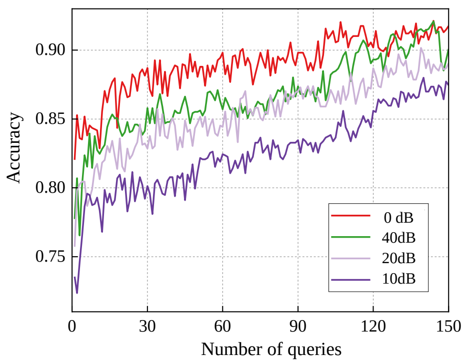

FIGURE 7. Classification curves of noised conditions.

Potential for application of results

SHM for complex structures has been a key research focus. Unlike long-span bridges or frame structures, spatial grid structures have numerous components and complicated spatial layout, thus bringing difficulties in damage detection related work. In this thesis, the author proposed a novel damage identification framework that has the potential of utilization in SHM for complex spatial structures, taking the grid structure as an instance, mainly in those following aspects:

1) ***Data anomaly detection***: SHM for spatial structures inevitably brings significant amount of data samples to be processed. The author's LAL-AdaBoost algorithm could be a brand-new approach for data preprocessing because much manual labelling work will be saved avoiding biased classification. In future research, more challenging data anomaly patterns are expected thus this methodology could be further developed to process the monitored data of both dynamic and statistic responses of the spatial structures.
2) ***Damage features extraction***: normally, the more complex the target civil structure, the more difficult it can be to use modal parameters to locate the inner damages. Therefore, the damage index proposed in this thesis has the potential to adapt to various in-situ conditions for it considers both the structural response (acceleration, e.g.) as well as the sensor layout, which may replace the traditional point of view regarding to damage location research.
3) ***Damage detection and location***: as is discussed in this thesis, LAL-AdaBoost is more than just a high-performance classification machine. In fact, it has the advantage of reducing manual labelling work, which has great potential of application for structural pattern recognition, after all it can be hardly possible to evaluate the structural status in every monitoring periods. By extracting only few representative samples, LAL-AdaBoost can achieve rather satisfying results, since spatial structures may appear multiple damage scenarios.

References

The following journal or conference papers that the author contributed to are given for reference of the proposed methodologies in this thesis.

[1] **Dang DZ**, Xu J. An ensemble learning-based structural damage identification method using acceleration data [C]. In proceedings of the 8th International Conference of Vibration Engineering, Program of Structural Dynamics and Control, Shanghai, China. 2021.7. DOI: 10.26914/c.cnkihy.2021.016464.

[2] Xu J, **Dang DZ**, Ma Q, Liu X, Han QH. A Novel and Robust Data Anomaly Detection Framework using LAL-AdaBoost for Structural Health Monitoring [J]. Journal of Civil Structural Health Monitoring, 2022. DOI: https://doi.org/10.1007/s13349-021-00544-2