# CHAPTER 8

# HEALTH MONITORING SYSTEM FOR THE STRUCTURAL MONITORING AND DAMAGE DIAGNOSIS

## 8.1 Introduction

Methods of structural identification, and automatic damage detection and health monitoring for smart structures have received more significant attention. This work attempts to provide a framework of health monitoring system for a smart structure. To achieve this goal, the system identification, damage detection, and conditions monitoring methods, as well as a series of shaking table tests of a four-story building structure were proposed and conducted. In this chapter, how these methods play roles in a health monitoring system is overlooked.

An ideal system for structural health monitoring is considered to be able to perform the following tasks:

(1) On-line recording of various types of structural vibrations;

(2) Extraction of structural modal parameters and vibratory characteristics from the recorded signals to be used in monitoring and diagnosis;

(3) Assessment of structural condition based on the obtained modal parameters

and damage related dynamic characteristics;

(4) Issuing a warning message and providing proper strategic decisions if potential damage is confirmed.

In implementing the foregoing tasks, some important issues need to be clarified and solved. In performing the first task, it is capable of recording the monitored observations on-line based on modern sensing and storage equipments and techniques. However, types and numbers of sensors, especially optimal deployment of sensing stations should be determined in advance. The selection of the types and numbers of sensors is associated with the cost and the theories adopted in health monitoring methods; while the optimal selection of sensing locations is another important and complicated topic for the structural control or health monitoring of large civil structures. In this research, two types of observations (i.e. structural acceleration and strain) were monitored through the use of accelerometers, RSGs, and FBG sensors. Due to the relative simplicity of the experimental specimen to real structure, the number of the sensors that installed on the experimental specimen is not too much. The problem of finite sensors does not need to be considered herein. However, it is indeed necessary to be considered for complex structures since the number of available sensors is always much lesser than the total DOFs of the structure.

For the second and third tasks, there are numerous methods can be employed. If the model-based methods are adopted, the location and extent of damage in a structure can be identified and estimated; however, the accuracy and reliability of the analytical model need to be ensured. If the non-model-based methods are utilized, the uncertainty and error of the analytical model are avoided, while the damage location especially the damage extent will be difficult to diagnose. Since every developed method has its own specific advantages, the strategy that integrated with different types of methods for dealing with the second and third tasks would be suited and promising. In this work, the condition of a structure is designed to be monitored in certain ways. The structural characteristics, such as natural frequencies, displacement mode shapes, and strain mode shapes, were obtained from the response observations by the system identification model. Considerable changes in structural characteristics imply possible damage in the structure. The structural characteristics provide direct monitoring on the structure; however, the location of damage can not be identified due to the global nature of the structural characteristics. Consequently, the method that can identify the damage locations according to the damage features (or patterns), which were based on the structural characteristics, is used to provide local nature on the damage condition. The foregoing methods for monitoring structural health in global or local way rely on certain mathematical or analytical models. If they are not robust enough to deal with the uncertainties and errors, the applications of them would be limited. Therefore, the monitoring strategies that do not need mathematical or analytical models, such as global and decentralized monitoring networks were also involved in this work.

The health monitoring system will try to make decisions (how to react based on the diagnostic results, in other words) in performing the fourth task. In doing so, the assessment results from the third task should be passed through the corresponding criteria or thresholds to produce more precise and meaningful warning. How to determine the thresholds is another question need to be investigated and is not discussed in this work.

## 8.2 An Integrated System For Structural Health Monitoring

Following the foregoing guidelines of implementing the four tasks, a feasible structural health monitoring system that integrated with several essential mechanisms is organized in Figure 8.1. The mechanisms that involved in the integrated system are the structure monitoring, the system identification, the damage diagnosis, and the warning mechanisms. In the structure monitoring mechanism, the global and decentralized monitoring networks are involved in; the ANNSI model holds the key position in the system identification mechanism; and ANN-based damage localization approaches are involved in the damage diagnosis mechanism. The health monitoring system is designed to be independent of the type of dynamic signature used for monitoring or the type of structure concerned.

Before the health monitoring system is used for structural monitoring and damage diagnosis, it is initialized in advance. The health monitoring system is initialized in the following steps:

(1) The deployment of the sensing stations is the first step in initializing the system. To make the system more efficient, the algorithms or methods for optimal placement of sensors are fundamental to be investigated if finite sensors are available [69, 101, 131]. Without optimization of sensors locations, the location of sensing stations is basically determined on basis of knowledge of the weak links in the structure (i.e. to place the sensors near the expected damage locations).

(2) An analytical model for representing the real structure is developed if the health monitoring methods is model-based. And the analytical damage features (such as ADLFs in this research) are generated by the analytical

model to form a part of the baseline data. In this step, the analytical model should be updated according to the measured information to make it more suitable for representing the real structure.

(3) When the healthy structure is vibrated by the external forces, such as earthquakes and winds, the sensors record the structural responses in real time. Simultaneously, the recorded responses are inputted to the monitoring and system identification mechanisms to generate the other parts of the baseline data. The baseline data in this step are the learned weighting matrices of the global and decentralized monitoring networks, and the modal parameters (including natural frequencies, damping ratio, displacement mode shapes, and strain mode shapes) of the intact structure. Additionally, as the system identification model is based on a neural network (termed as modal analysis network, MAN), the learned weighting matrices of the MAN in this step can be used as the initial values in the next identification iteration to save time in training the network.

After the health monitoring system was initialized, it is ready to perform the core tasks of the system, i.e. structural monitoring and diagnosis. In every diagnosis cycle, the damage diagnosis mechanism will yield the possible damage assessment of the new observations by the three strategies described in Chapter 7. Refer to Figure 8.1, the operation in every diagnosis cycle is described as follows, in detail.

(1) When the structure suffers new excitation, the new observations (including the structural acceleration and strain measurements, and input excitation) from the instrumented sensors are simultaneously contributed to the monitoring mechanism in which the global and decentralized monitoring

networks are involved and the system identification mechanism where the ANNSI model is included. Then the structural behaviors can be monitored by the initialized global and decentralized monitoring networks to yield the prediction errors for the new observations. Furthermore, the new observations are also analyzed by the ANNSI model to obtain the modal parameters of the target structure of current state.

(2) The damage diagnosis mechanism, where the two-stage ANN-based damage assessment approaches were involved, will yield quantitative or qualitative assessments on the possible damage based on the modal parameters changes and the prediction errors obtained from the last step. For examples, the increasing prediction error from the global monitoring network (refer to Section 4.5.1) gives rough diagnosis (such as the existence of damage) on the deteriorated structure; the prediction errors from the decentralized monitoring networks (refer to Section 4.5.2) and the strain mode shape changes (i.e. CSMS presented in Section 7.4) provide easy classification on the damage location by using non-model-based methods; the UFN damage localization approach (refer to Section 5.2) yields more accurate and local damage site by using the model-based method; furthermore, estimation of the damage extent is accomplished at the second stage relying on the identified damage location which was identified at the first stage by using the estimation algorithms (refer to Section 5.3).

(3) If the diagnostic results show possible damage in the structure, they are contributed to the warning mechanism, in which certain decision criteria and thresholds are included, to perform proper decisions and handlings. On the

contrary, if the diagnostic results show no or insignificant damage in the structure, the baseline information (including the weighting matrices in the monitoring networks, the baseline modal parameters, and the analytical model which generates the ADLFs instance base) will be updated by the new observations.

Notably, since the proposed system is mainly organized by neural networks, some information of the previous diagnosis cycle can be used for the next cycle. For example, in addition to the weighting matrices in the monitoring networks and the MAN of ANNSI model can be used as initial values for the next cycle, the diagnosis data (such as the measured DLFs) can be added to the ADLFs instance base to update the instance base. This step makes the system adaptive, i.e. the network will be able to detect the damage accurately if it occurs a second time. This will result in the network performance to improve with time since it will get more diagnosis experiences from the routine monitoring.

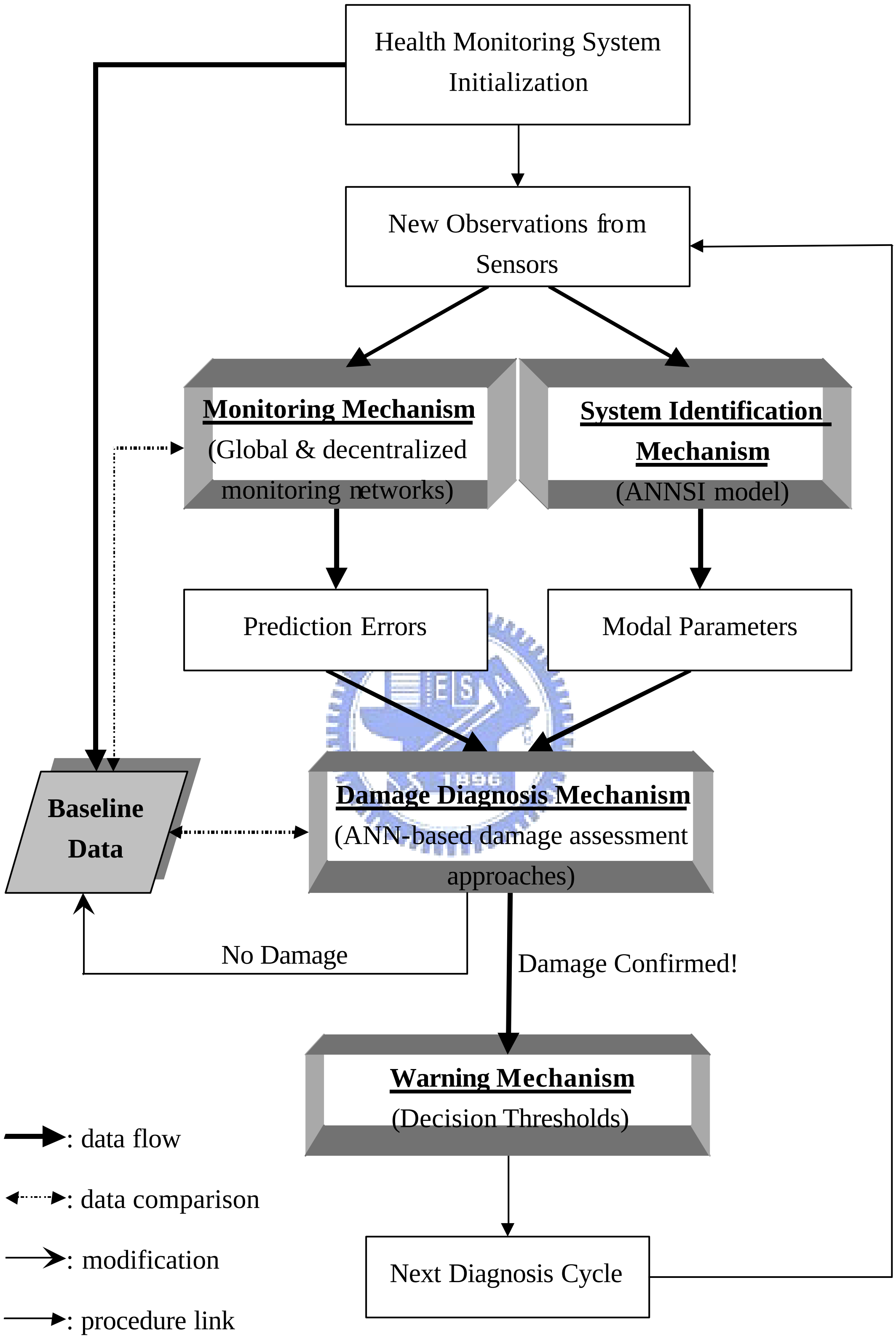


**Figure 8.1** Operation of the integrated health monitoring system