# A Study on Software Framework of Structural Health Monitoring System Based on NEESit

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**ABSTRACT:**
In this paper, to meet the needs of application about structural health monitoring (SHM) system，a new software framework of SHM (SHMSF) is proposed. System integration techniques are studied on the basis of designs and implementations of SHM system of practical projects. The methods of the design and implementation for software framework are used to confirm the architecture for SHM system. The structure and operational mechanism of NEESit are introduced, and the application of NEESit functional modules related to SHM system is analyzed. This kind of software framework makes the work including data sharing, reciprocal access and coordinated test possible under the condition that connected real projects with NEES, moreover, it could be applied to different kinds of SHM systems by its good universality.

**KEYWORDS:**
structural health monitoring, software framework, NEESit

## 1. INTRODUCTION

With the increase of important-large civil project and the occurrence of engineering accident, the structure's health is becoming more and more important. It is no surprise that structural health monitoring (SHM) has increasingly become a very active research filed in recent years. SHM is a approach to continuously collect data about critical structural elements using sensors to monitor and assess the condition of the structure, the sensory data includes loadings, stresses, strains, accelerations, temperature, and video signal, etc. (Darbani, et al., 2007). How to acquire, process, store and analyze the massive amount of data becomes the main issue which is facing the SHM community, and then the software framework that can be applied to different kinds of SHM is proposed for that issue. In computing, a software framework provides "the skeleton of an application that can be customized by an application developer"(Ralph E., 1997). To develop the “skeleton” of SHM (software framework of structural health monitoring system, SHMSF) is not an easy thing, because of the characters of SHM such as real-time and long-distance data transmission, various data processing and analysis methods, and kinds of processing results. NEESit is found to facilitate the development of the framework, which includes software tools and makes fifteen geographically distributed experimental equipment sites and a central data repository connected to the global earthquake engineering community. The software tools of NEESit have been used for structural health monitoring on the Voigt Bridge over Interstate 5 in San Diego, can archive and view accelerometer data and video data of the bridge in real time, and establish communication between the bridge and NEES . It provides an excellent example of the application of NEESit in SHM. In China, the Open Platform for Simulation of Earthquake Engineering Damage (SEED, the Chinese version of NEES) is being built, the construction of the platform will learn from NEES's technologies and experiences, which is scheduled to be published in 2010 and connected to foreign related systems in 2011, such as NEES and E-Defense. SHMSF can be applied to many kinds of SHM systems, and also can be connected to NEES and the future SEED to get much more services including data sharing, reciprocal access and coordinated test, etc, and will foster the development of practicable SHM methodologies.
This article will introduce the design of SHMSF based on NEESit, including the system integration, architecture design and implementation technologies.

## 2. THE COMPOSITIONS OF SHM

Although many SHM systems have different monitoring contents, processing and analysis methods, and compositions, etc., four subsystems must be integrated, they are: 1) Sensory subsystem; 2) Signal acquisition and processing subsystem; 3) Data transmitting subsystem; 4) Data management and analysis subsystem. Such as the SHM system for the Nanjing Yangtze River Bridge consists of three subsystems: sensory subsystem, signal sampling and processing system, and structural monitoring and condition assessment system (Huang ,et al.,2002); the Wind and Structural Health Monitoring System (WASHMS) is used to oversee the integrity, durability and reliability of the Tsing Ma, Ting Kau, and Kap Shui Mun bridges which consists of six subsystems: sensory subsystem, data acquisition and transmitting subsystem, data processing and control subsystem, condition assessment subsystem, portal data acquisition subsystem, computer maintenance subsystem(LIU Zheng-guang, HUANG Zhao-you, 2005).

Figure 1 shows the relationship of the four subsystems, and the components and functions can be summarized as follows:

(1) Sensory subsystem is a network of heterogeneous sensors, which measures the acceleration, displacement, strain, temperature, wind speed and visual information, etc. ,the network must be easy to deploy, scalable-allowing for progressive deployment over time, and must allow for local processing and filtering of data, remote data collection, accessibility and control (Fraser, et al., 2003).

(2) Signal acquisition and processing subsystem composed of data acquisition cards, data acquisition server(DAQ Server), video server (hardware), etc., collects the signals from sensory subsystem to files, does some preliminary works such signal condition, A/D conversion, local storage.

(3) Data transmitting subsystem composed of data transmitting server, receives data (sensory data and video data) from signal acquisition and processing subsystem, transmits data among remote data base, analysis subsystem, and other application systems, and makes data transmittance based on internet stable and efficient.

(4) Data management and analysis subsystem consists of database server, application server (APP server), and Web server. Sensory data, project information, system information, and user information, etc. are stored in data base, various transaction process components such as data management, user management, damage identification methods and structure condition assessment should be included, and user interface also should provided.

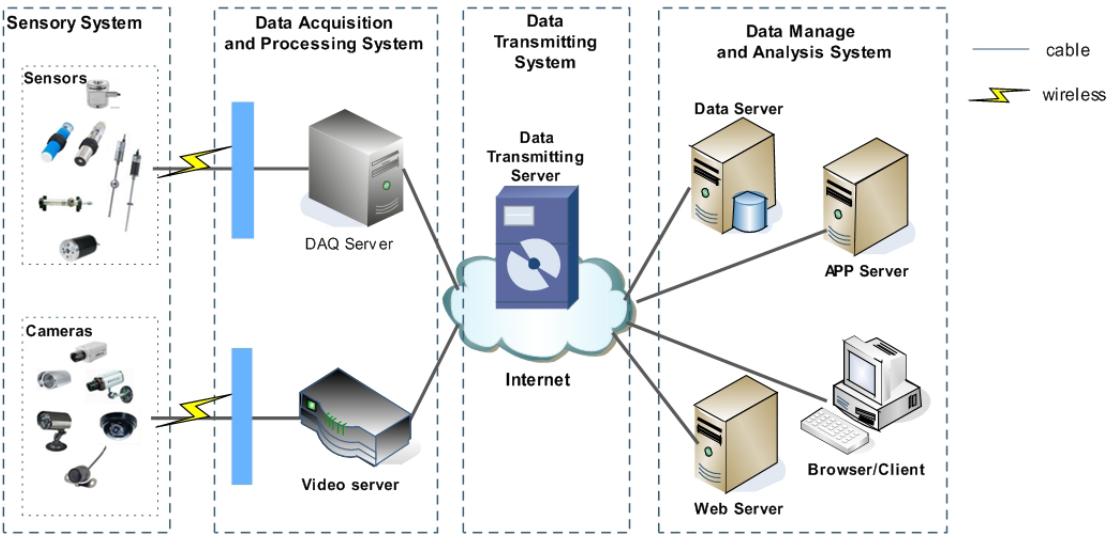


Figure 1 Prototype of integrated SHM

## 3. ARCHITECTURE DESIGN OF SHMSF

The software architecture of a program or computing system is the structure or structures of the system, which comprises software components, the externally visible properties of those components, and the relationships between them (Len Bass et al., 2003). The design of software architecture focuses on both functional requirements as well as different architectural quality attributes such as flexibility, performance, reusability, testability, and usability. The multilayer technology can be used to simplify the process of architecture design, and divides the software into several layers; layer is a logical structuring mechanism for the elements that make up the software solution.

The layers of software must meet the following principles (See Figure 2):

(1) Each layer is constructed of classes and components, to complete specific functions.

(2) The relationship between the top layer and down layer is that only the top layer can call down layer's Application Programming Interfaces (APIs) and the down layer can not get any services from the top layer's components.

(3) Each layer gives public APIs to the top layer, but its implementation details are hidden;

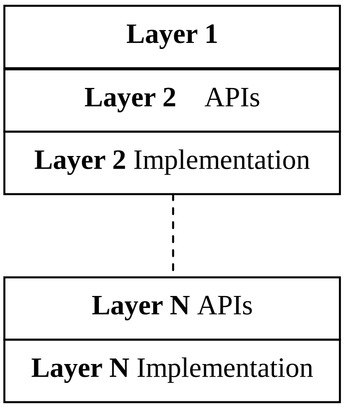


Figure 2 Top layer accesses the down layer through public APIs.

According the components and functions of the four subsystems and the architecture principles, the multi-layer of combining B/S (Browser/Server) model and C/S (Client/Server) model is choosed as the architecture of SHMSF. In this architecture, data management and analysis subsystem should be divided in to three layers, consists of presentation layer, business logic layer and persistence layer, and the data base, data transmitting subsystem, data acquisition subsystem and processing subsystem and sensory subsystem are considered as the data sources and designed as the system basis. Beside the layers of the software framework, the privilege security management has also to be considered.

The relationship of layers is shown in the Figure 3, the following is a list of the logical components features:

(1) Presentation layer

Presentation layer is the topmost layer of the application, represents the interface between the user and the application, deals with issues like how to receive the users' requests, delivers the requests to business layer, and displays processing results from the business layer; in this layer of SHMSF, web browser and client are used for B/S model and C/S model to interact with users, respectively.

(2) Privilege Security Management

To ensure the safety of the system, users of the system are divided into two classes by privilege security management, i.e. managers and data processing and analysis (DPA) users, each user also has different services based on his role in each class.

(3) Business logic layer

This layer separates the business logic from other layers, consists of many unaided business components, these components encapsulate reusable functionality and expose service APIs, in SHMSF, they are responsible for user management, data management, data processing and analysis (DPA), e.g., data management and maintenance, damage identification, reliability and risk assessment, etc., each component in this layer can be added, modified, deleted without changing other components.

(4) Persistence layer

This layer allows communication between business layer and data bases and keeps them independent, business components can be developed completely independent of the underlying data bases, and only data access operations should be permitted in this layer.

(5) Data sources

There are four kinds of data source in the architecture, including data from sensory system, data from data acquisition and processing system, data from data transmitting system and data from data base and files, but only the data base can be accessed by the persistence layer and the data transmitting subsystem can be accessed by the business logic layer considering other real-time applications such as real-time display, real-time analysis and real-time control, the other two kinds of data are hidden to the top layers.

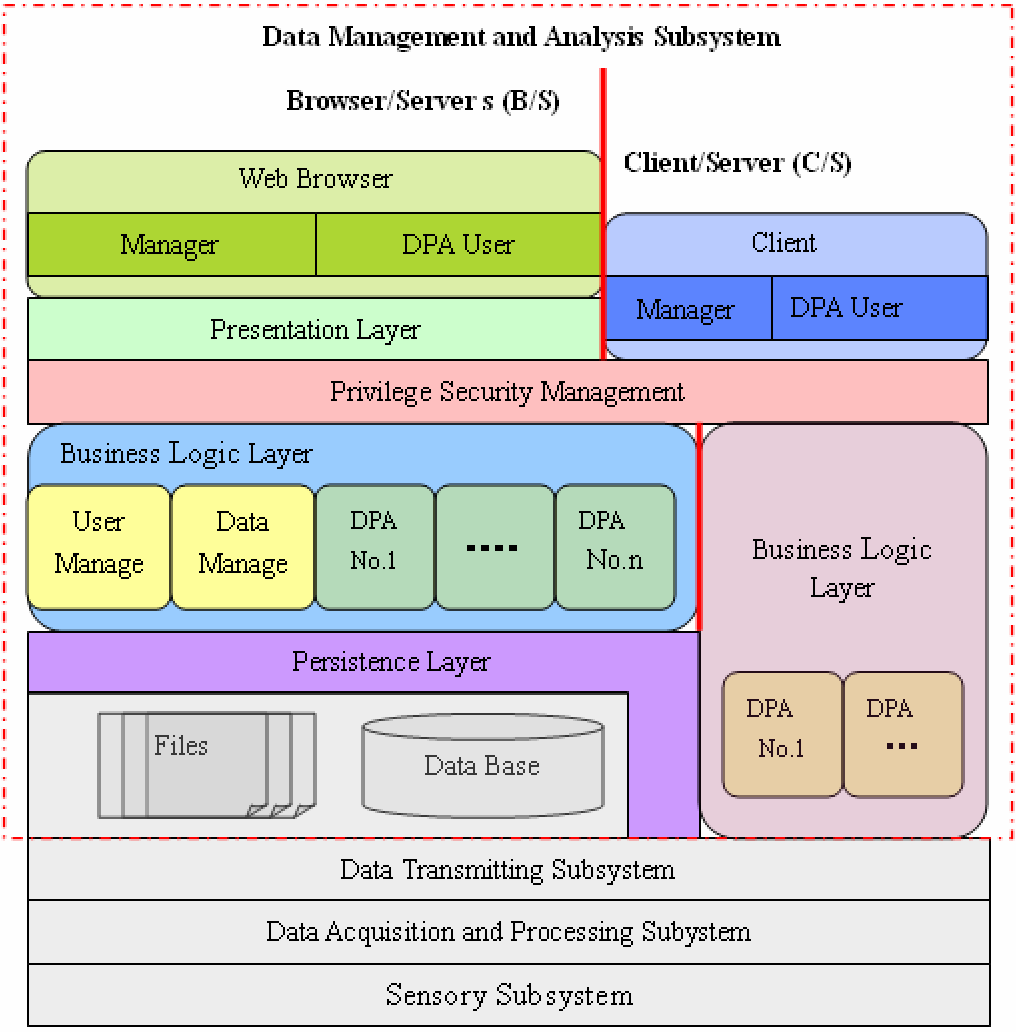


Figure 3 The logic architecture of SHMSF

## 4. IMPLEMENTATION TECHNOLOGY OF SHMSF

NEESit enables earthquake engineers to remotely participate in experiments, perform hybrid simulations, organize and share data, and collaborate with colleague through information infrastructure and technology tools. The software provided by NEESit, is Open Source Software, so every one can easily get its source codes and documents from NEESit's Web site and do secondary development. The software tools of NEESit are classified according to their function or by where they are installed and configured in the following classes: 1) Organize and Share Data, consists of NEEScentral, Presentation Software, NEESit Google Earth™, etc.; 2) Participate in Meetings and Events, consists of WebEx and Internet2 Commons; 3) Perform Hybrid Simulations, consists of NTCP for Matlab and NHCP; 4) Participate in Remote Experiments consists of the Real-time Data Viewer (RDV), NEESdaq, and Data Turbin, etc.. NEEScentral is a web-based centralized data repository for managing, sharing, storing, and publishing data. RDV provides an interface for viewing real-time, synchronized, streaming data from an equipment site. NEESdaq utilizes the LabVIEW™ platform to stream sensor data to Data Turbine. Data Turbine works behind the scenes to store streaming data for later playback with RDV, the relationship of them is shown in Figure 4.

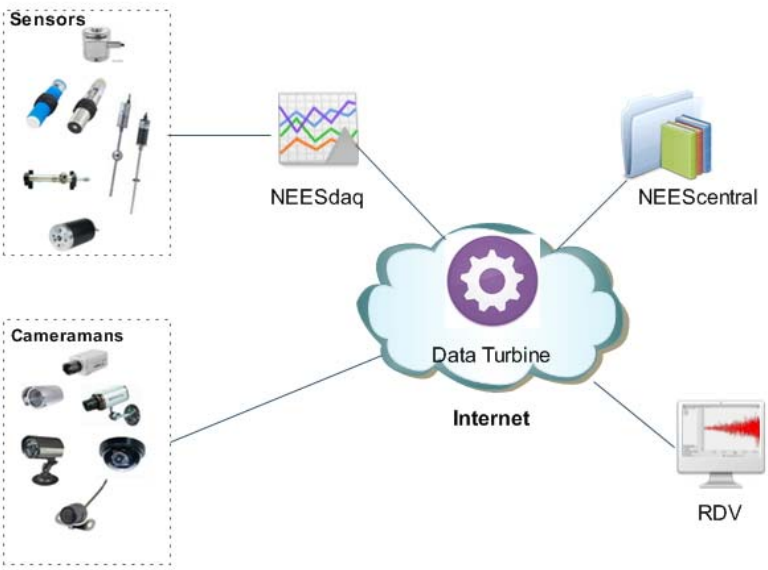


Figure 4 The relationship of NEESdaq, Data Turbine, NEEScentral and RDV in NEESit.

To compare Figrure 2 and Figure 4, the correspondence of responsibilities is easily found, NEESdaq can be is assigned to Signal acquisition and processing subsystem, Data Turbine can be is assigned to Data transmitting subsystem, NEEScentral and RDV can be is assigned to Data management and analysis subsystem.
According to multilayer architecture of SHMSF and the correspondence between SHMSF and NEESit, the implementation technologies of SHMSF are introduced as the following:

(1) Presentation layer.

This layer is deployed in Apache Tomcat Web server. Apache Struts and Cewolf are used to implement the B/S model, Java rich-client application can be used to implement the C/S model, and Java Web Start is used to deploy the java rich-Client applications. In reality, RDV which provides an interface for viewing real-time, synchronized, streaming data from an equipment site was developed by the technologies of the java rich-client application and Java Web Start, so it can be easily employed as client in the SHMSF.

(2) Privilege security management.

This management is deployed in each part of the SHMSF. Role-based security is used to implement it. Role-based security allows administrators to assign access permissions to users based on the roles they play rather than on their individual identities. It also explains the relationship between Enterprise Java Bean (EJB) -scoped, application-scoped, web-application scoped and global security roles.

(3) Business logic layer.

This layer is deployed in JBoss application server. EJB is used to implement this layer. EJB is the server-side component architecture for Java Platform, Enterprise Edition (Java EE). EJB technology enables rapid and simplified development of distributed, transactional, secure and portable applications based on Java technology.

(4) Persistence layer.

This layer is deployed in JBoss application server. Hibernate is used to implement this layer. Hibernate is a Professional Open Source project, an object-relational mapping (ORM) library for the Java language, providing a framework for mapping an object-oriented domain model to a traditional relational database. Hibernate solves Object-Relational impedance mismatch problems by replacing direct persistence-related data base accesses with

high-level object handling functions.
(5) Data source.
The data structure and file hierarchy of NEEScentral will be used to design the storage of SHMSF., Data Turbine will be used to implement data transmitting subsystem and also can be seen as the bridge of SHMSF and NEES, and NEESdaq can be used to implement the data acquisition subsystem.

## 5. CONCLUSION

The proposed software framework based on NEESit will provide an efficient and powerful SHM system. It can allow user focus on data analysis methods rather than deal with low-level details of system (e.g., how to get the data from sensors, how to store data, and how to display data, etc.). It also sets up connection between monitored structure and NEES to implement more meaningful works including data sharing, reciprocal access and coordinated test, etc.. The design of the framework promises great scalability in terms of both extensibility and portability. Additional modules, such as more advanced structural damage detection and condition assessment components, can be integrated into the framework conveniently. The advantage of JAVA as the implementation technology is platform independence of the framework.
In the future, the framework will be implemented and applied to practical projects, and more data analysis functions will be integrated into this software framework to support more sophisticated structural condition evaluation.

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