Safety Assessment System of Launching Tower Structure with Multi-information Fusion and Data-driven

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Abstract. In order to monitor and evaluate the impact of rocket launching shock, strain, vibration, typhoon, earthquake and other loads on the launch tower, an online monitoring and evaluation system was established based on multi-sensor information fusion technology in a space launch site. Firstly, the system integrates the information of vibration, pressure, deformation, wind load, temperature and other sensors to comprehensively analyze and evaluate the safety of tower structure, and realizes health diagnosis. Then use 3dmax to draw the 3D simulation model, and realize the real-time 3D display of various monitoring and analysis results based on the 3D visualization and data-driven technologies.

1. Introduction

Launching tower is one of the most critical ground equipment in space launch site, which is mainly composed of service tower, rotary platform, diversion channel and ancillary facilities and equipment, and is typical large steel structure building. During the rocket launch, the tower will suffer from rocket shock, flame ablation, stress release, mechanical fatigue, alternating load and other extremely complex and harsh environmental tests, and its safety and reliability will certainly be affected. Because its safety, stability is directly related to the success or failure of the rocket launching, it is particularly important to monitor and evaluate the health of tower structure.

Structural safety monitoring is to continuously monitor the key parameters the building through certain sensors, which provides an important basis for the health assessment and reliability analysis. Structural safety monitoring is of great significance for timely detection of potential safety hazards in buildings, structural damage and residual life assessment of structures after accidents, which has been widely used in health assessment of large bridges. Large span bridges, such as Tsing Ma Bridge, Xupu Bridge and Donghai Bridge have adopted structural safety monitoring systems of different scales and achieved good health monitoring results[1,2].

Based on the successful experience of structural safety monitoring in the field of bridge, this paper uses vibration, strain, pressure sensors to monitor the tower, and carries out time-frequency domain analysis, fatigue analysis and modal analysis on the monitoring results[3,4]. Through 3dMax modeling and OSG, a tower structure safety assessment system is designed and implemented based on multi-information fusion and data-driven.

2. System Constitution

The system consists of six modules: data acquisition, data communication, data storage, data analysis and processing, 3D visualization and user interaction, as shown in Fig. 1.
1) The data acquisition module monitors the key parts of the tower in real time by using pressure, vibration, wind load, strain, temperature and other sensors, and sends the data to the front-end IPC through the acquisition instruments.

2) The data communication module is used for the data communication with the database and the monitoring system, including the data transmission link of protocol and frame format, receiving, transmitting and parsing the data for storage and analysis.

3) The data storage module stores the massive data received and collected in a distributed way to ensure the availability, integrity and security of the data.

4) The data analysis and processing module prepossess the collected data, such as filtering, waveform reconstruction and so on. Based on the building structure monitoring, and analyzes the data to obtain various characteristic values, such as time domain, frequency domain, auto-correlation, cross-correlation and wavelet. Finally, the health status is obtained through expert knowledge, machine learning and pattern recognition methods.

5) The 3D visualization module loads and displays the 3D models of the tower structure, all kinds of equipment and sensors. And updates the status of all kinds of sensors based on the data-driven mode, so as to provide a more intuitive and realistic display effect.

3. Analysis and evaluation system with information fusion
Multi-sensor information fusion refers to the synthesis of information generated by multiple or multiple sensors at different locations of the same target, eliminating possible redundancy and contradictory information among sensors, complementing each other, improving their reliability, so as to form a relatively complete and consistent perceptual description of the target[5]. In order to get
more accurate and deeper structural security information, the system not only analyzes the data of each type of sensor to obtain various characteristic parameters, but also fuses the multi-sensor data.

3.1. Real-time acquisition and transmission of multi-sensor signals
In addition to collecting the parameters of the tower structure itself, the system also needs to collect many kinds of external system data, such as atmospheric salt fog, platform control signals and so on.

1) Design of sensor distribution
There are mainly fiber grating strain sensors, vibration sensors and impact pressure sensors, based on the minimum configuration, staggered layout of the barrier, key parts of the key monitoring principles to achieve a comprehensive monitoring of the tower. Fiber-optic grating strain sensor is arranged in the complex stress and stress concentration parts of the fixed service tower. The vibration acceleration sensors are arranged at the pillar corners of the front and back ends of the fixed service tower. The pressure sensors are uniformly arranged on the inner side of the column beam of the fixed platform corner of each layer on the front side of the tower, and the sensitive surface of the sensors is facing rocket direction, which directly bears the impact of the combustion airflow.

2) Sensor Data Acquisition
According to different sensor acquisition characteristics, vibration monitoring acquisition system and dynamic micro-pressure acquisition system are set up, and each subsystem is composed of acquisition instrument, vibration sensor, signal transmission cable, industrial Ethernet hub and other components. By setting the sampling frequency of daily operation state and test state, the effective utilization of resources can be achieved.

3) Other data acquisition
In addition to monitoring the vibration, pressure, deformation and temperature data of the tower structure, the system receives the state data of the opening and closing angle of the tower platform, the water tank liquid level, platform and the environmental monitoring data of the temperature, humidity, wind speed and salt fog around the tower, realizes the unified storage of the structural data and environmental data, and facilitates the correlation analysis of the data.

3.2. Subsystem data analysis
For the data of vibration, pressure and strain, the processing and analysis methods such as time-frequency domain analysis, structural fatigue analysis, ODS analysis and modal analysis are mainly used:

1) Time-frequency domain analysis of vibration, strain and impact pressure
The vibration, pressure and strain signals collected are analyzed in time domain, frequency domain, auto-correlation, cross-correlation, wavelet and envelope spectrum, and batch processing and eigenvalue extraction can be realized.

2) Structure Fatigue Analysis
The structural damage degree and structural fatigue were analyzed by rain-flow counting, peak counting and variable range counting, which provided the basis for the study of structural life trend.

3) Analysis of strain
The strain ODS technology can display the stress and strain of each measuring point of the measured object intuitively in the form of cloud map, and at the same time, the contour cloud map is given by interpolation calculation[6]. Thus, the static load test can get rid of the boring figures, realize the animation display function, and provide a real-time analysis and evaluation method for load control.

4) Modal Analysis of Tower
The modal parameters of the tower structure can be obtained through the modal analysis with EMA, OMA modal test and other modal fitting methods, such as least square complex frequency domain method, stochastic subspace method SSI and enhanced frequency domain algorithm EFDD.
3.3. Multi-information fusion analysis

There is a high degree of coupling between the data of all kinds of data. In order to achieve the fusion of multi-physical field characteristics of the tower, and provide data support for fault diagnosis, the system prediction and safety assessment of the tower structure based on multi-sensor data information and various phenomena characterization of the tower for comprehensive analysis. The main approaches are as follows:

1) Construct the continuous information

Although the sensor array arranged on the tower is large in scale, the detection points of the sensor can’t achieve the full coverage of the tower structure. In order to reconstruct the spatial continuous signals of strain, vibration and pressure around the tower, the state characteristics of the global structure of the tower can be observed in more detail and intuitively. The system uses Kriging interpolation algorithm to reconstruct the signal on the basis of the collected sensor point signal.

2) Comparative Analysis of Multiple Tasks Data

By comparing the variation trend of tower vibration, deformation frequency, amplitude, damping and other parameters obtained by tower structure monitoring system during multiple launching tasks, the health state of tower can be predicted and managed, and the number of times when a certain position reaches the failure limit can be obtained. In addition, when the signal monitored by a launch mission changes significantly compared with previous launches, the system needs to check and maintain the abnormal position of the tower for early warning.

3) The simulation of multi-physical field

During the launching process, there is a strong coupling effect between multiple physical fields in the tower system. In order to evaluate the service limit of the tower accurately, the finite element method is used to simulate the tower structure. The boundary conditions and initial conditions of the system are obtained from the recorded sensor signals. The physical fields involved in the simulation include structural deformation field, structural vibration field, temperature field and wind field.

4. 3-D visualization based on data-driven

At present, in virtual reality technology, the OSG has been widely used in the field of game scene rendering, military simulation and scientific visualization because of its good modularity, ease of use and cross-platform features[7,8]. The data-driven mode can realize the real-time updating of the 3D visualization scene and model, and display all kinds of data and the structural characteristics of the tower intuitively in real time. And including the three-dimensional driving layer, message processing layer and application layer.

4.1. Model Construction and Rendering

By acquiring various sensor data and using three-dimensional scene modeling and data-driven mode, the vibration, strain and pressure of steel structure buildings in typhoon, platform action and launching process can be displayed or reproduced in real time, which provides intuitive analysis and judgment for building safety state monitoring. The specific steps are as follows:

1) The 3D structural model of the building in the field is established with the 3D graphics technology, which fully shows the real-time state of the steel structure building from multiple angles, and intuitively shows the layout status of the steel structure building from various angles.

2) According to the characteristics of various sensors, different rendering methods are designed, and the three-dimensional rendering function of OSG is used to add.

3) Add the sensor models according to the position of each sensor in the OSG world coordinate system.

4.2. Data-driven

The data acquisition module converts the original signal preprocessing into the data of vibration, pressure, deformation, platform opening and so on. And then transmits them to the 3D visualization module. The action and state of each structural component according to the sensor data collected in
real time. Mainly, it can realize the real-time display of the vibration direction and amplitude of each layer of the tower, the deformation size of each steel structure part, and the pressure direction and size of each part. And it can realize the opening and closing of steel structure platform, water filling of water tank and other animation processes.

4.3. Real-time analysis and display
The monitoring data display system is developed based on OSG engine and QT programming tool. In order to ensure the synchronization and smooth display and rendering of multi-type 3D data, GPU parallel acceleration (CUDA) is used. The system displays and monitors the local three-dimensional situation of a tower as shown in Fig. 2, with a simple and friendly interface. Fig. 3 is the radar chart of the system for the deformation characteristic data of a building, which can make the abnormal position obvious and facilitate the fault location.

Fig. 4 shows the time-frequency domain analysis of the vibration signal of the tower in a certain part of a physical field, which can obviously find that there is abnormal vibration in this part, which needs to be observed and prevented.

5. Summary
In this paper, based on multi-information fusion and 3D visualization, an online monitoring and evaluation system for the tower structure is built. The system comprehensively utilizes the data of vibration, pressure, deformation, temperature and other sensors to analyze and evaluate the safety of tower structure. The real-time 3D display of various health conditions of the tower based on data-driven mode has achieved good results. The construction of the system has important military and economic significance for improving the construction level of space launch site, improving the safety and reliability of space launch tower structure and reducing the cost of management and maintenance.

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