Design of Airborne Real-time Monitoring System for Vibration Signal of Large Civil Aircraft

Liang Jiayi
Instrumentation Department
COMAC Flight Test Center
Shanghai, China, 201323
Liangjiayi003@163.com

ABSTRACT

The high frequency vibration signal can effectively reflect the structural strength of aircraft during flight test. In order to meet the need of real-time monitoring of vibration parameters of a large civil airliner, an airborne real-time monitoring system for vibration signals is designed and developed. Development of airborne real-time monitoring software for high-frequency signals was based on C#. The software received and analyzed the network data of the airborne acquisition system, processed the time domain signals by FFT and power spectrum transformation, and realized the graphical display. The software can provide a strong support for the monitoring person to know the status of the aircraft in time.

INTRODUCTION

Real-time monitoring enables flight test engineers to grasp and judge the safety of aircraft in time status and the reliability of aircraft systems during flight test, which provides an important support for flight test safety[1]. Vibration is an important indication that mirrors the strength and reliability of aircraft structure. 90% of structural strength failure of aircraft is caused or related by vibration[2].

Vibration parameters have the feature of high sampling rate, large amount of data and complex processing[3]. It is currently analyzed and processed after flight test.

Based on WPF(Windows Presentation Foundation) framework, an airborne real-time monitoring system for vibration parameters is introduced in this paper. The system receives and parses the network packet data from the airborne vibration signal acquisition system, then the original data is processed by FFT(Fast Fourier Transform) and PSD(Power Spectral Density), transferred in time domain signals, and displayed real-time in graphical interface. The software enables flight test engineers to have a clear understanding of the aircraft's vibration state. It provides a powerful support for the flight test security.

AIRBORNE NETWORK COMMUNICATION

Vibration signal real-time monitoring system consists of vibration sensors in extra refitting, signal acquisition board of airborne test system and real-time data processing monitoring software. Flight test engineers use airborne monitoring terminals to monitor aircraft vibration in real time. The signal acquisition system gets vibration sensor data by mature products of TTC

(Teletronics Technology Corporation) and send in NPD (Network Products Division) network packet format.

NPD network data package is an airborne test system defined by TTC Company, which acquires data transmission message protocol through Ethernet data acquisition network. NPD message protocol is on application layer. It runs under the standard IPv4 network and UDP transmission protocol, and uses UDP multicast for data transmission. The packet structure is shown in the “Figure 1”.

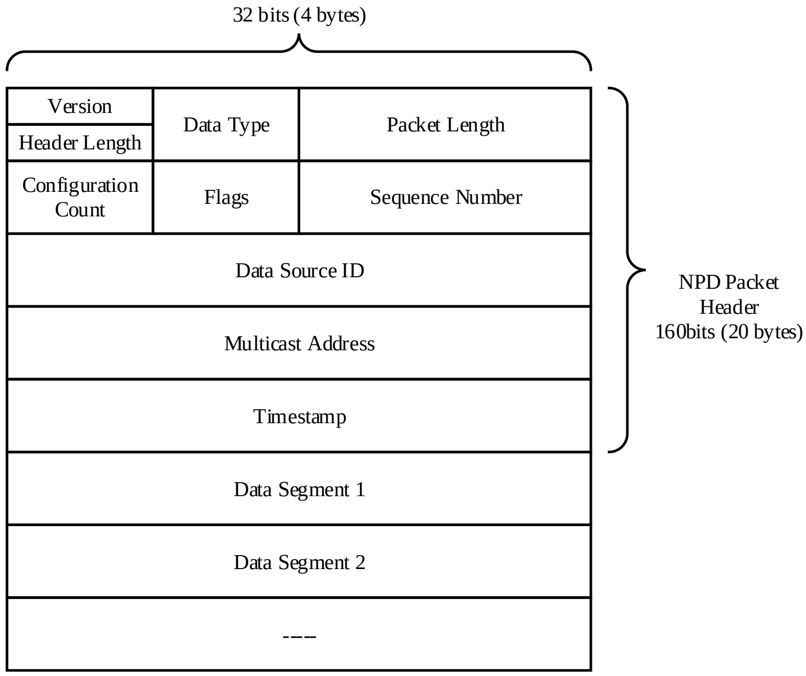

Figure 1 NPD data packet.

Each network packet contains a NPD header followed by one or more data segments. Each segment has a segment header and a segment body. The segment contains the acquired data. The structure of each data segment is shown in the “Figure 2”.

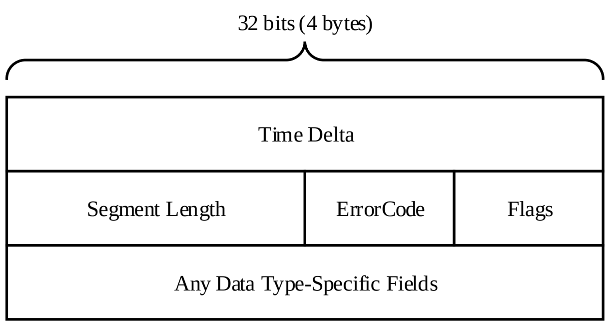

Figure 2 Segment header values.

VIBRATION SIGNAL REAL-TIME MONITORING SYSTEM SOFTWARE

The function of the real-time monitoring system software for vibration signal is to analyze the data from the collector, convert the engineering value, perform the second operation and real time reflect in time domain and frequency domain. It consists of data processing module, real-time analysis module and visual display module.

Data Processing Module

The function of the data analysis module is to real time receive the NPD network data package sent by the vibration signal acquisition system, to extract the parameters of the data stream, to convert the engineering value, and to send the engineering value results to the real-time analysis module for real-time data calculation and visualization display module for time-domain signal display.

Firstly, the configuration of the collector is loaded, and the configuration information and parameter information of the collector cabinet are stored in the cabinet information structure and the parameter information structure. The UDP socket is created by the chassis information structure, which receives the network packet data, and extracts the original code value of the parameters in the PCM data stream according to the parameter information structure, and converts the engineering value. The calculated parameter and physical value are sent to the real-time analysis module and the visual display module in events. The software flow pattern is shown in the "Figure 3".

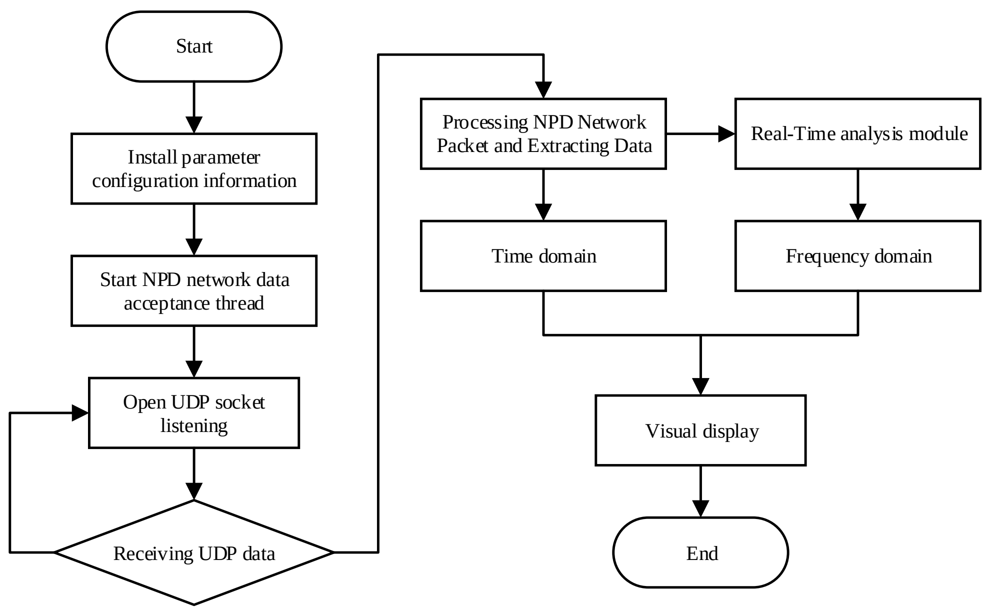

Figure 3 Software flow pattern.

Real-Time Analysis Module

Based on flight test requirements, the system integrates two typical vibration data analysis methods, FFT(Fast Fourier Transform) analysis and PSD(Power Spectral Density) analysis.

FFT is a fast method for computing discrete Fourier transform. For sequences $x_0, x_1, x_2 \cdots x_{n-1}$, its Fourier transform can be expressed as:

$$y_j = \sum_{k=0}^{n-1} e^{-\frac{2\pi jk}{n}} x_k \qquad j = 0,1,2 \cdots n-1 \tag{1}$$

It can be seen from the upper form that to complete the Fourier transform of the sequence, n^2 complex multiplications and $n(n-1)$ complex additions are needed. FFT decomposes a signal sequence of length $n = 2^m$ into odd order and even order. Therefore, the discrete Fourier transform of *x(n)* can be expressed and calculated by the discrete Fourier transform of *n/2* sampling points. The discrete Fourier transform of sequence *x(n)* can be expressed as：

$$x(k) = \sum_{r=0}^{\frac{n}{2}-1} x_1(r) W_{n/2}^{kr} + W_n^k \sum_{r=0}^{\frac{n}{2}-1} x_2(r)\, W_{n/2}^{kr} \tag{2}$$

$$W_n^k = e^{-\frac{2\pi kj}{n}} \tag{3}$$

PSD is defined as the signal power in the unit frequency rang. It represents the change of signal power with frequency, that is, the distribution of signal power in frequency domain[4]. For a finite random signal sequence x(n), its FFT and PSD content the following formulas:

$$\widehat{S_x}(f) = \frac{1}{N} |x(f)|^2 \tag{4}$$

In the formula, *N* is the length of the random signal sequence *x(n)*. At the discrete frequency point *f=k⊿f* there are:

$$\widehat{S_x}(k) = \frac{1}{N} |X(k)|^2 = \frac{1}{N} |FFT[x(n)]|^2\,, \qquad k = 0,1,2,\cdots,n-1 \tag{5}$$

FFT[x(n)] is a Fourier transform of sequence *x(n)*.

Visual Display Module

The time domain signals output by Data Processing Module and the analysis results output by real-time analysis module are displayed by visual display module. Visual monitoring screen helps flight test engineers intuitively grasp the structural strength state of the aircraft. The monitor screen is shown in the “Figure 4”.

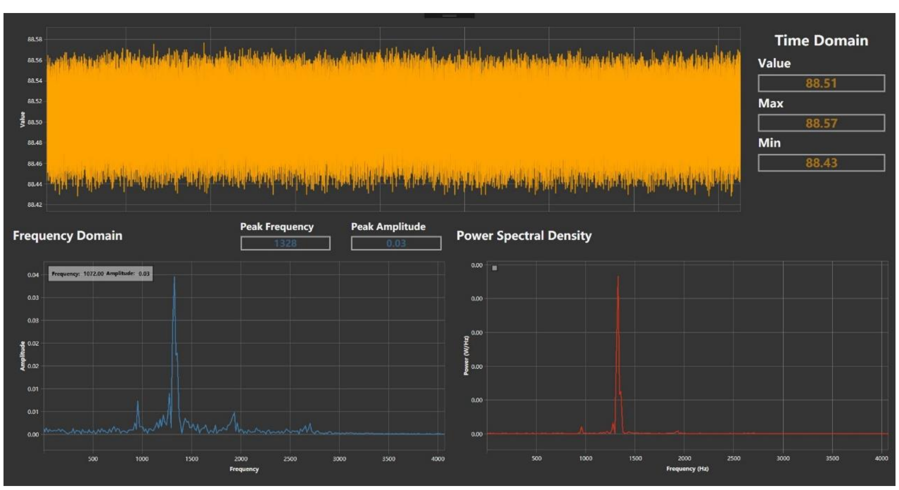

Figure 4 Monitor screen.

CONCLUSIONS

Vibration signal real-time monitoring system has been verified by experiments. The refresh rate of the system is 8192 Hz, and the system delay is less than 150ms.

The vibration signal real-time monitoring system introduced in this paper has successfully supported flight tests of large civil airliners.

1) Real-time extract and analysis the high-frequency data in NPD network packets.
2) Time domain calculation and power spectral density estimation are completed in real time, which provides effective analysis results for real-time monitoring.
3) Visual display of vibration signal in time domain and frequency domain provides effective support for real-time monitoring during flight test.

REFERENCES

[1] Zhuohui Wu, Research on Airplane Flight Safety Real-time Monitor Software based on Real-time Database, Nanjing, Nanjing University of Aeronautics and Astronautics, China, 2006.

[2] Chaohui Huo, The Desing and Implementation of Telemetry Real-time Processing System of Airborne Flight Test Vibration Paramentrs,Xi'An, Xidian University,China,2012.

[3] Xiaoya Li and Manting Liu, Realtime Processing of Vibration Signal in Flight Test,Modern Electronics Technique, vol 34(13), pp. 81-83, Jul. 2011.

[4] Minliang Zhou and Zhongming Chen, Research on Vibration Fatigue Life Frequency-Domain Estimation Method of Aircraft Structure, Aircraft Design, vol 37(3), pp.25-30, Jun.2017.