Frequency conversion sampling technology based on vehicle triggered bridge deflection response

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Abstract. According to the multi-time characteristics of deflection and deformation of operating bridge structures, trigger control strategies were applied to bridge deflection sampling control, which breaks the periodic constraints of existing deflection sampling technologies. On that basis, we present an on-demand sampling method to achieve deflection deformation low-frequency sampling when the response amplitude is small, and high-frequency sampling when the response amplitude is large. This method fully collects the dynamic deflection peaks, reduces the number of sampling points significantly, and relieves the system pressure, reduces hardware resource consumption, and extends the system’s service life. This study will provide a reference for real-time frequency conversion sampling.

1. Introduction

The deflection signal of operating bridges has multiple scales of time. When there is no car or car passing, the signals are steady-state signals which can be sampled at low frequencies to reflect the deflection deformation trend. When a heavy vehicle passes, the deflection monitoring signals change greatly and are regarded as transient signals which requires high-speed sampling. The peak points of the signals are collected to facilitate real-time safety warning of vehicles crossing the bridge.

The adoption of low-frequency sampling methods will cause distortion of the vehicle load response data; while adoption of a single high-frequency sampling method will inevitably affect the operating efficiency and resource utilization of the monitoring system, increase the server’s operating load, and cause communication congestion. In order to reduce consumption of resources, the periodic constraint can be removed, and the vehicle trigger control strategy can be applied to the real-time online monitoring of bridge deflection, so that the sampling frequency changes with the time scale of the deflection signal, thereby reducing the number of sampling. This method can alleviate the system pressure, reduce hardware resource consumption and extend system’s service life.

2. Frequency conversion sampling trigger mode and sampling time

2.1 Frequency conversion sampling trigger mode
Vehicle information survey results show that 90% of China’s port container trailers are 1.5 meters in height. Containers of 1.55-1.6 meters high account for only a small part, and 1.3-meter-high bulk containers are also rare, and the chassis height is 1.2-1.5 m. In this study, 2.5 m is selected as the monitoring condition. When the vehicle height is greater than 2.5 m, the frequency conversion sampling is triggered. According to the survey results of vehicle identification technology, the frequency conversion sampling trigger mode selects external triggering (radar wave, laser scanning technology) and three methods based on response of characteristic parts.

1. Radar wave or laser scanning technology: The recognition system is installed at the bridge head, the height is 6.0 m from the road, and the radar wave recognition height is 3.5 m. When the height of the vehicle exceeds 2.5 m, the high-frequency sampling mode is triggered. The radar wave and laser scanning technology are suitable for all bridges that are open to traffic in one direction.

2. Response of characteristic parts: The mode is triggered by the deflection response of the vehicle crossing the bridge, and high-speed sampling when the vehicle response is greater than the set limit. The characteristic part response technology is suitable for multi-span bridges. A trigger displacement sensor is installed in the first span of the bridge. When the displacement response value reaches the preset limit, high-frequency sampling of all sensors across other bridges is triggered.

2.2. Sampling duration
The sampling duration can be determined according to the bridge span S and the design vehicle speed V where the sensor is farthest from the trigger point, t=S/V, and the sampling duration is extended by 2 seconds on the basis of the sampling time t.

If the vehicle identification system needs to trigger high-frequency sampling according to the vehicle identification result, the front-end high-frequency sampling mode is triggered immediately. According to the preset application frequency and sampling time, the high-frequency sampling will be resumed when the vehicle leaves the maximum bridge span where the sampling sensor is located. If the high-frequency sampling unit is not triggered, then no frequency conversion is required, and the non-trigger state sampling is continuously performed, and the vehicle type recognition is continuously performed through the vehicle type recognition system until a vehicle requiring high frequency sampling appears.

3. Development of a frequency conversion sampler

3.1. System architecture design
The high-frequency sampling method is triggered if the vehicle detection technology detects a heavy vehicle. That is, the front-end high-frequency sampling unit is triggered: according to the preset sampling frequency and sampling duration, the non-trigger state is resumed when the vehicle to drive away from the largest bridge where the sampling sensor is located for sampling. If the high-frequency sampling unit is not triggered, no frequency conversion is required; the non-trigger state sampling is continued, and the vehicle detection technology continues to be used for vehicle identification until the vehicles that require high-frequency sampling appear, and the collected data is uploaded to the server through the 4G network. The overall system architecture is shown in Figure 1.
3.2. Development of the system’s functional modules

A vehicle-triggered bridge load response frequency conversion sampling device consists of a vehicle type identification device, a variable frequency acquisition device, a wireless transmission module, and a host computer. The vehicle type identification device 1 transmits real-time identification and classification signals of a vehicle to a frequency conversion sampling device 2 as a trigger for the frequency conversion sampling device 2; the frequency conversion sampling device 2 can change the data sampling frequency in real time, thereby realizing the storage of frequency conversion signals transmitted from device 1. The frequency conversion sampling device 2 communicates with the host computer 4 through the wireless transmission module 3. The frequency conversion sampling device 2 transmits the signals collected by the frequency conversion to the host computer 4 through the Module 3, and the host computer 4 displays and saves the data in real time; At the same time, the host computer 4 transmits the preset configuration control signals such as the frequency conversion sampling frequency, sampling channel and trigger logic to the device 2 through Module 3, and configures Device 2 accordingly.

(1) **Front trigger unit**

This trigger system uses the millimeter wave mine method as the front-end trigger, and distinguishes heavy vehicles from light vehicles by identifying the shape of the vehicle through a millimeter wave radar, when a heavy vehicle passes through the front-end trigger section, the millimeter-wave radar passes an analog comparator to compare the signals with the triggering signals. By adjusting the position of the signal input terminal and the trigger level terminal, positive/negative crossing trigger can be realized.

(2) **Variable sampling frequency data acquisition unit**

The variable sampling frequency data acquisition system adopts a design scheme combining a single chip microcomputer and an FPGA. The system frame diagram is shown in Figure 2. According to the triggering logic, the FPGA controls the sampling frequency: the analog signal is conditioned and sent to a high-speed A/D converter. The control logic inside the FPGA implements the control and data storage of the high-speed A/D conversion, and then transmits the data externally through a wireless transmission module. The data acquisition system first performs front-end processing on the collected signals, such as signal amplification, filtering, and DC level shifting, to meet the requirements of the A/D converter for analog signals. The FPGA module mainly implements trigger logic identification, high-speed ADC control, and data storage.
Figure 2. Architecture of the frequency conversion acquisition unit

The frequency conversion data acquisition module consists of an embedded real-time module (RT), an FPGA chip, and a lower computer module with 4 differential input AD acquisition channels and 1 DI digital signal acquisition channel. By running a real-time program on the RT system of a lower computer, the lower computer responds to the trigger signal and changes the sampling frequency of data acquisition in real time. At the same time, the RT system program can transmit data to the host computer through wireless WiFi in real time.

Major technical indicators are as follows:
- High sampling frequencies: 100Hz, 1000Hz, 2000Hz, 5000Hz
- Low sampling frequencies: 0.01Hz, 0.02Hz, 0.05Hz, 0.1Hz, 1Hz
- Number of AI communication channels: 4
- ADC resolution: 16 bit
- Input range: ±10V, ±5V, ±2V, ±1V
- Number of triggered channels: 1
- Triggering logic: low: -0.3V~0.8V; high: 2V~5V

(3) Host computer software

The sampler can be used independently, or multiple units can be connected to form a multi-channel test system. The data sampling device establishes communication between the computer and the sampler instrument, and then sets the system’s parameters.

The following steps are required: set the system parameters, set the gateway IP to the server IP address determined in advance; set the remote IP to this port under the server IP address; set the local IP to the same frequency band as the remote IP. The hotspot name is set to the field industrial router name; the hotspot password is set to the field industrial router password, and other parameters need not to be set. Click and write in the parameters.

For setting of sampling parameters, the start channel and end channel are set according to the actual situation on site. The sampling modes include three types: single sampling, continuous sampling and trigger sampling. In single sampling, the sampling device collects 1S data according to the set sampling frequency; in continuous sampling, the sampling device samples continuously according to the preset sampling frequency until the sampling mode is changed in the software; in trigger sampling, the sampling device performs sampling at a preset sampling interval when no triggers are received, and when the trigger signal is received, the sampling device samples for a period of time according to the preset sampling frequency. In this case, the sampling time is the preset time. After the device samples for a period of time, it returns to the non-trigger state for sampling, and other parameters need not to be set, and the parameters will be written into the software.

(4) Communication protocol

The capture card supports the TCP Client and TCP Server modes. In general, the capture card works in the TCP Client mode which can connect multiple capture cards to a data server. The remote
data server works in the TCP Server mode, responsible for monitoring the capture card that is connected to the server. The data service program is responsible for realizing the data transmitted from multiple sampling cards into the database, and forwarding the data to other applications or web servers to visualize the data. The number of default ports of a remote data server is 7000, and the number of ports of a capture card is 7000. The second is to work in the TCP server mode, a high-speed mode. The computer is connected to the sampling card as a client. After data sampling starts, the data is continuously sent to the computer. A special client program is designed on the computer side to receive high-speed data, acquire data, perform real-time waveform display, spectrum analysis, or record the acquired data to a binary file. The default number of the monitoring port of the sampling card is 7000.

4. Engineering practice verification

4.1 Determination of trigger device installation position, sampling duration and sampling frequency

The trigger device is installed at a distance of 10 m from the bridge head, the height is 6 m from the road surface, and the vehicle height exceeds 2.5 m to enter the trigger range. High-frequency acquisition is initiated. The sampling distance of this bridge is 10m + 170m = 180m, the vehicle travels at a speed of about 40 km/h, and spends 16.2 s crossing the bridge. After the vehicle crosses the bridge, it samples signals for another 3 s, thus the sampling time totals 19.2 s. The trigger device is shown in Figure 3.

The original bridge base frequency is 1.645 Hz. In order to avoid distortion of signals, the sampling frequency is 8 to 10 times the base frequency. Finally, the high-frequency sampling frequency of the bridge is determined to be 20 Hz and the low-frequency sampling frequency is 1 Hz.

![Figure 3. Trigger device diagram (unit: cm)](image)

4.2 Test result analysis

The collected data curves in Figure 4 show that the sampling frequency is 1 Hz when no heavy vehicle passes, and the frequency increases to 20 Hz when a heavy vehicle passes. This saves the space for data storage and facilitates data processing.

![Figure 4. Test result curves](image)

5. Conclusions

Through the research on the technology of frequency conversion sampling for deflection of small- and medium-span bridges, our study solves the problem of data distortion caused by a single sampling frequency mode or redundant mass data. The method proposed herein can achieve effective and complete sampling of key data with guaranteed efficiency. Based on simple data processing and
analysis, it can detect abnormal conditions of deflection and deformation timely, accumulate materials for long-term damage identification of bridge structures, and improve early warning of bridge safety damages. It will provide technical support for bridge maintenance and management.

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