Bridge Structural Health Monitoring Using 23 Accelerometers: Feasibility Assessment and Data Acquisition System Architecture

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Abstract

Structural Health Monitoring (SHM) systems for bridges increasingly rely on continuous vibration measurements to evaluate structural behavior, identify changes in modal characteristics, and provide early warning of deterioration. This paper considers representative deployment using 23 accelerometers, each sampled at 100 Hz. In this application, the primary engineering challenge is not the sampling frequency itself but rather the requirement to collect, time-synchronize, and manage data from 23 independent accelerometer sensors. This paper evaluates different Campbell Scientific data acquisition architectures, including serial expansion, distributed data acquisition, RS-422/RS-485 multidrop networks, and analog-output accelerometers paired with high-speed analog measurement modules. The advantages and limitations of the different system architectures are presented.

1. Introduction

Bridge monitoring applications frequently utilize accelerometers to measure dynamic responses arising from traffic loading, wind excitation, seismic activity, and structural vibration. The acquired data is subsequently used for:

- Modal analysis
- Structural condition assessment
- Damage detection
- Fatigue evaluation
- Long-term performance monitoring

The proposed monitoring system consists of:

- 23 accelerometers
- Continuous acquisition
- Sampling frequency of 100 Hz

The challenge lies in integrating a large number of serial digital sensors into a centralized monitoring platform while maintaining synchronization and data integrity.

2. System Requirements

The project requirements can be summarized as follows:

Parameter	Requirement
Number of Accelerometers	23
Sample Rate	100 Hz
Application	Bridge Structural Monitoring
Data Synchronization	Required
Continuous Logging	Required
Remote Monitoring	Desirable

The requirements imply that the data acquisition system must simultaneously receive measurements from all twenty-three sensors, accurately timestamp the measurements, and store or transmit the collected data for further analysis.

3. Understanding the RS-422 Communication Challenge

RS-422 is a differential serial communication standard designed for high-noise environments and long cable lengths. It is widely used in industrial and structural monitoring applications because of its robustness and immunity to electromagnetic interference.

However, unlike analog sensors that can be connected simultaneously to multiple input channels, each RS-422 sensor generally requires an independent communication channel unless specifically designed for multi-drop operation.

For a system involving twenty-three independent RS-422 devices, the acquisition platform must:

- Maintain communication with 23 independent serial streams

- Poll or receive data from each sensor
- Handle communication timing
- Prevent data collisions
- Synchronize measurements across all devices
- Manage large quantities of incoming serial data

The complexity therefore grows with the number of sensors rather than with the sampling frequency itself.

4. Capabilities of the CR1000Xe

The Campbell Scientific CR1000Xe provides flexible communication capabilities and supports RS-232, RS-422, RS-485, SDI-12, Ethernet or TCP/IP communications. The logger creates RS-422 or RS-485 communications using combinations of its control terminals.

Key strengths include:

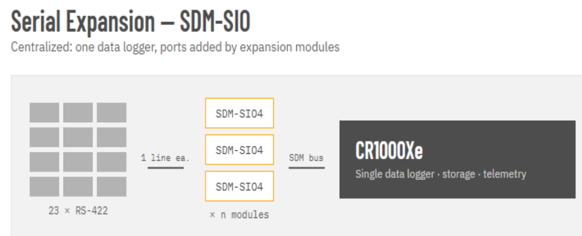
- Deterministic data acquisition
- High reliability
- GPS synchronization capability
- Edge processing
- Local data storage
- Remote communications

However, despite its powerful processing capabilities, a single CR1000Xe does not inherently provide twenty-three dedicated RS-422 ports.

Consequently, direct connection of 23 independent RS-422 accelerometers to a single CR1000Xe is generally not practical without additional expansion hardware.

5. Architecture Option 1: Serial Expansion Using SDM-SIO Modules

Concept
Additional serial communication ports can be provided using Campbell Scientific SDM-SIO serial expansion modules.



Architecture Option 1: Serial Expansion Using SDM-SIO Modules

Advantages

- Retains centralized architecture.
- Utilizes existing Campbell Scientific ecosystem.
- Simplifies data storage.
- Single monitoring point.

Challenges

- Large number of expansion modules required.
- Increased installation complexity.
- Additional configuration effort.
- Higher hardware cost.

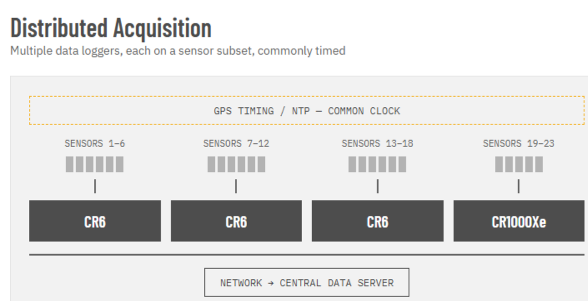
Suitable When

- Sensor count is moderate.
- Physical installation space is available.
- Centralized architecture is preferred.

6. Architecture Option 2: Distributed Data Acquisition System

Concept

Deploy multiple Campbell Scientific data loggers such as CR6 or CR1000Xe. Each logger acquires data from a smaller subset of accelerometers.



Architecture Option 2: Distributed Data Acquisition System

All loggers are synchronized through:

- GPS timing
- Network Time Protocol (NTP)
- Common timing source

Advantages

- Improved scalability.
- Reduced communication burden per logger.
- Easier troubleshooting.
- Improved system redundancy.

Challenges

- Multiple dataloggers required.
- Additional synchronization strategy necessary.
- More complex network architecture.

Suitable When

- Large sensor networks are deployed.
- High reliability is required.
- Long-term infrastructure monitoring projects are involved.

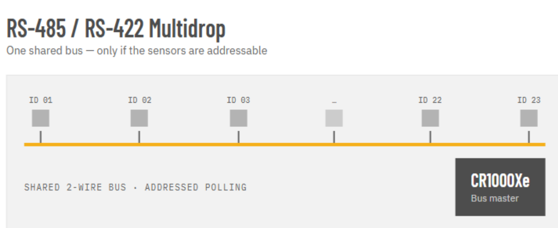
7. Architecture Option 3: RS-485 / RS-422 Multidrop Network

Concept

If the accelerometers support:

- Node addressing
- Multidrop communications
- Bus architecture

then all sensors may be connected on a common serial bus.



Architecture Option 3: RS-485 / RS-422 Multidrop Network

Benefits

- Significant reduction in wiring.
- Lower hardware requirements.
- Simplified network architecture.

Considerations

Before adopting this approach, the manufacturer must confirm:

- Device addressing capability.
- Bus communication protocol.
- Polling methodology.
- Maximum node count.
- Maximum cable length.

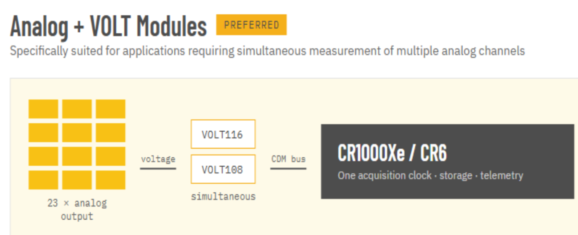
Suitable When

- Sensors support true multidrop operation.
- Network design permits shared communication channels.

8. Alternative Approach: Analog Accelerometers

A potentially simpler and more robust solution is the use of **analog-output dynamic accelerometers**.

Unlike RS-422 sensors, analog accelerometers produce continuously varying voltage signals that can be measured directly by high-speed analog acquisition hardware.



Alternative Approach: Analog Accelerometers with VOLT108 / VOLT116

9. Analog Acquisition Using VOLT108 and VOLT116

Campbell Scientific offers high-speed analog measurement modules such as VOLT108 or VOLT116. These modules are specifically suited for applications requiring simultaneous measurement of multiple analog channels.

Advantages

Simplified Wiring

No serial communication protocol management is required.

True Simultaneous Sampling

All channels can be sampled synchronously.

Reduced Integration Complexity
No sensor polling routines are necessary.

Improved Time Synchronization
Measurements originate from a common acquisition clock.

Easier Maintenance
Field diagnostics become significantly simpler compared to troubleshooting multiple serial communication networks.

10. Comparison of Approaches

Criteria	Multiple RS-422 Sensors	Analog Accelerometers + VOLT Modules
Communication Complexity	High	Low
Synchronization	Moderate Complexity	Excellent
Expansion Requirements	Significant	Minimal
Wiring Complexity	High	Moderate
Maintenance Effort	High	Low
Scalability	Moderate	High
Data Integrity	Good	Excellent
System Cost	Potentially Higher	Potentially Lower

11. Recommended Solution

For bridge structural monitoring with many accelerometers at 100 Hz, the preferred solution depends primarily on whether sensor selection is flexible.

If you can select sensors: use analog-output accelerometers + VOLT108/VOLT116 + CR6/CR1000Xe. This provides the cleanest implementation, best synchronization, and lowest long-term operational complexity.

If RS 422 sensors must be used (in order of preference):

- **Distributed CR6/CR1000Xe** architecture with a defined synchronization method (e.g., GPS or NTP where appropriate).
- **RS 422/RS 485 multidrop bus** (only if the sensor manufacturer supports true addressing + multidrop protocol).
- **SDM-SIO serial expansion** (useful, but can become complex at 23 independent channels)

12. Conclusion

Acquiring data from many accelerometers at 100 Hz is well within the capabilities of Campbell Scientific data acquisition systems. In most bridge structural health monitoring deployments, the limiting factor is not sample rate. It is system architecture, specifically the practical burden of implementing and sustaining twenty-three independent RS-422 communication paths in the field.

When RS-422 sensors are required, proven approaches include serial expansion to increase available ports and distributed acquisition to reduce cable runs and segment the system into manageable nodes. Both strategies can meet the performance target, but they introduce additional considerations around network topology, channel management, timing alignment, and long-term serviceability.

Where sensor selection is flexible, analog-output accelerometers paired with high-speed analog input modules such as VOLT-series modules offer a substantially cleaner implementation. Removing dozens of concurrent serial data streams reduces protocol handling, polling and throughput constraints, and channel-to-channel timing uncertainty. This makes the overall system easier to synchronize, maintain, troubleshoot, and scale over multi-year monitoring campaigns.

For large-scale bridge structural health monitoring programs where reliability, repeatability, and time correlation across channels are essential, architecture choices should prioritize communication simplicity and deterministic acquisition behavior, rather than focusing solely on accommodating a high count of digital serial links.