APPLICATION NOTE

Structure health monitoring (SHM)

Today, society has built a countless number of buildings, sometimes with complex architecture designs. Long-term monitoring, also known as SHM, has a high degree of importance when the structures are subject to heavy physical loads, ageing, and other external factors that appear after construction (e.g. corrosion, seismic damage).

The SHM technique involves the installation of many sensors fixed to critical areas in order to track internal strains, microscopic deformations and frequency responses. In theory, any building can be monitored; however, some are a lot more exposed to danger than others, including:

- Dams
- Towers
- Bridges
- Skyscrapers
- Historical buildings

Figure 1 shows the impact of a vibrating load applied to a structure: any stress below the dashed line doesn't modify the integrity of the material: it is considered to be an elastic behavior, and the subject can theoretically operate indefinitely. In the other case, the number of cycles is defined before failure.

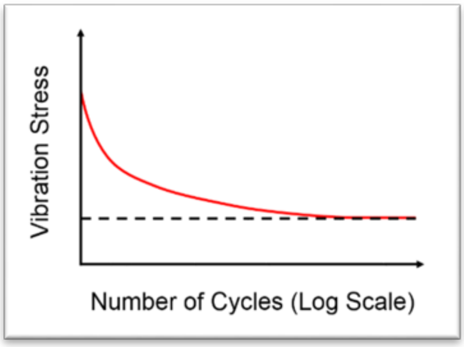

Figure 1: The fatigue diagram

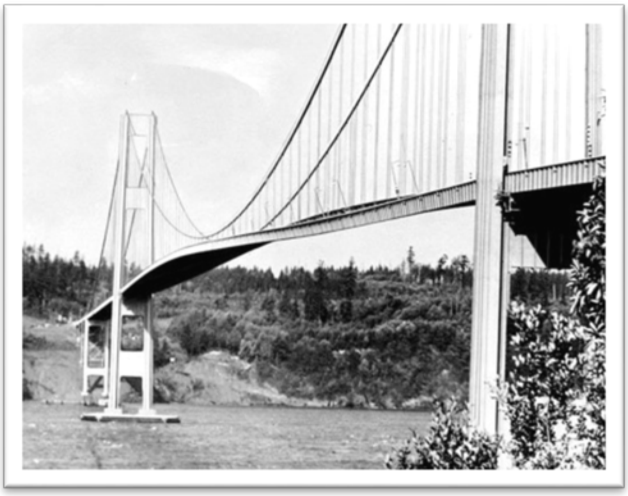
Figure 2: The Tacoma Bridge

Source from http://www.dcsfilms.com/Site_4/Tacoma_Narrows_Bridge.html

Long-term monitoring allows reacting in time before an accident occurs. The need for sensors is crucial to detecting faults. If cracks are visible to the naked eye, it means the structure is already in a critical state.

Whenever a structure is excited at a specific frequency, it can enter into a resonant mode. A famous example is the destruction of the Tacoma Narrows Bridge in 1940, due to this specific phenomenon: the wind caused the vibration of the whole structure, leading to its imminent collapse. Such an accident couldn't have been noticed during the construction of the bridge, in 1938.

The Wireless SHM Configuration

Two types of configuration can be selected when installing the sensors: the wired and the wireless networks. Although power supply is not a concern for the first method, the second method saves installation time, eliminates wiring costs and decreases the risk of communication breakdown. Wireless networking is divided into three categories, described in the figures below.

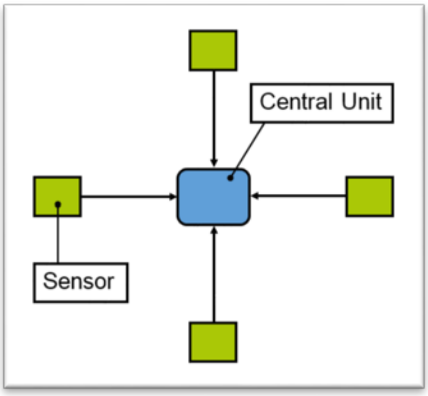

Figure 3: Server - Client

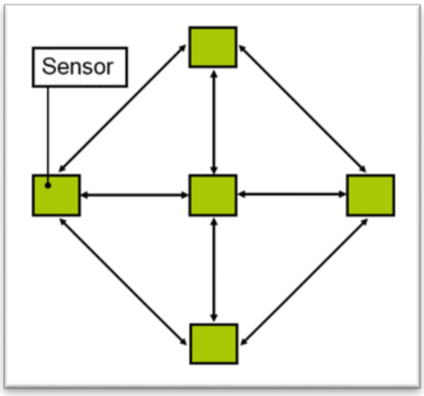

Figure 4: Peer-to-peer

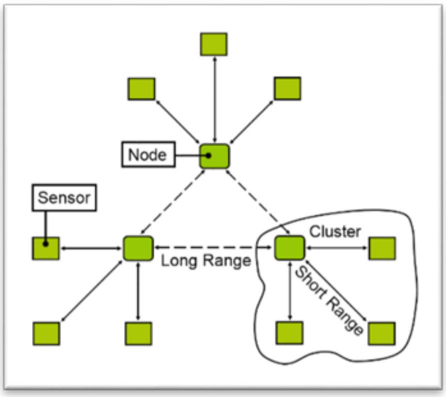

Figure 5: Two-tier

The two-tier configuration presents the best solution for wireless SHM: the sensors operate in clusters, and an integrated circuit (node) calculates and stores the data received either by its sensors or by other clusters. This allows reducing power consumption and maximizing data reception, as the transmission distance is drastically shortened. The main unit executes different algorithms, such as Discrete Wave Transform (DWT), Principal Component Analysis (PCA) or Damage Detection Index

(DDI) to generate a Self-Organizing Map (SOM). The SOM optimizes the communication path and displays the results of the whole sensing system.

Damage created in a structure inevitably causes a distinct vibration, which can be detected by an accelerometer. The embedded software applies the FFT algorithm to obtain the various frequencies observed by the sensors. The use of two sensors, one for each of the x and y axes is recommended.

Performance Required

The most important factor to consider in wireless SHM is power consumption. The system must function for at least a year to avoid high maintenance costs. The sensor must not only be reliable during its entire operating lifespan, but also accurately measure very small vibrations.

Bias derivation should be as low as possible. The sensors must endure daily temperature variations, and frequent on/off switching. If the sensors are not recalibrated by the system, the bias can exceed the critical level after a certain amount of time, and inevitably trigger a false alarm.

The Appropriate Sensor

The type and number of sensors partially depends on the configuration and on the duration of the monitoring. The legacy sensors for vibration analysis were the piezoelectric (PE) and piezoresistive (PR) sensors. They function through the use of a piezo crystal (e.g. PZT) and a proof mass. They have a very large frequency bandwidth: however, they cannot measure DC signals. Short-term wired monitoring and crash testing are typical applications where piezo sensors are implied.

More recently, MEMS capacitive accelerometers (VC) work according to the principle of mobile electric surface charges: the acceleration endured on the MEMS die forces a suspended beam to bend towards a positive or negative electrode, forcing the displacement of electrostatic charges. After electronic amplification, a voltage difference directly linked to the applied acceleration can be measured. This simple design greatly reduces power consumption, especially when it functions in an open-loop configuration. MEMS VC sensors are ideal for wireless long-term monitoring, as they offer portability, reliability and durability.

Safran Colibrys' Sensors

Safran Colibrys offers the VS1000 series, a new product line designed to deliver the best performance currently available in the vibration family. This accelerometer has the largest frequency bandwidth, capable of measuring signals typically from DC 0 Hz to 2500 Hz at ±5% FS, and up to 7000 Hz at ±3 dB. Although other ranges are available, the ranges considered for SHM would be ±2g, ±5g, and ±10g. It is one of the most accurate sensors produced by the company, with a spectral density down to 7 µg/√Hz, and a fixed non-linearity of 0.1% FS. The sensor operates at 10 mW, and it is estimated that it can function for 11 months, as long as it is powered by two AA batteries[1].

Figure 3: The VS1000 sensor

The VS9000 series trade accuracy for extra durability: it can operate for 16 months at least, in the same conditions as stated above. A graph showing the comparison of the two sensors for different operating power consumption is displayed on page 4. Finally, piezo sensors are not suited for wireless long-term SHM applications: they need a higher current to operate correctly, in general 2-20 mA for 10-24 V.

[1] Study based on http://resenv.media.mit.edu/classarchive/MAS961/readings/smart_structures.pdf , page 15-16

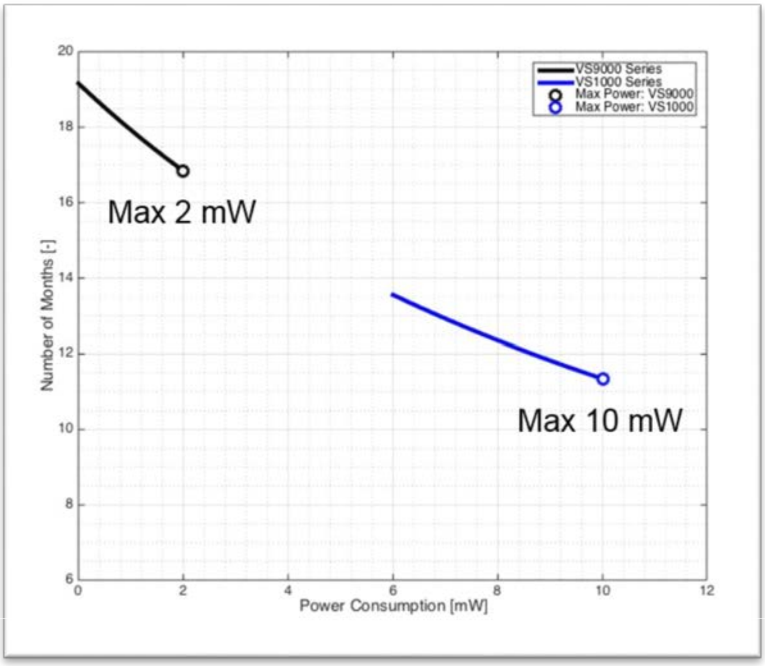

Figure 5: The lifespan of a SHM wireless module depends on the power consumption of the vibration sensors.

Glossary:

- dB: Decibel
- DC: Direct current
- DDI: Damage detection index
- DWT: Direct wave transform
- FFT: Fast Fourier transform
- FS: Full scale
- Hz: Hertz
- MEMS: Microelectromechanical systems
- PCA: Principal component analysis
- PE: Piezoelectric
- PR: Piezoresistive
- PZT: Lead zirconate titanate
- SHM: Structure health monitoring
- SOM: Self-organizing map
- VC: Variable capacitance