STRUCTURAL HEALTH MONITORING SYSTEMS FOR CRITICAL INFRASTRUCTURE

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This paper presents the structure and components of a general system of long-term static monitoring of the health of large critical structures and in particular the monitoring of works of art. The development of an integrated measurement system that provides a unified approach to the monitoring process stems from the lack of a comprehensive monitoring system on the market, that can include most of the measurement technologies used in the field nowadays and that can meet the general requirements for monitoring structures. The monitoring system described in the following pages integrates different measurement technologies into a single system, allowing power supplying different types of sensors, synchronized communication, as well as the acquisition and storage of measured quantities in a single, unified database.

Keywords: Structural Health Monitoring, Sensors, Static Monitoring, Works of Art

1. Introduction

A critical, large dimension structure designates a facility or infrastructure element with special purpose, used in various fields of activity and whose safety in exploitation and structural integrity is of paramount importance. This type of structure can be a bridge, tunnel, research or industrial facility, works of art, such as stadiums, historical buildings etc... These structures play an important role in the society and therefore comes the necessity of monitoring their health during construction and exploitation, anticipating potential risks and taking preventive measures and decisions in order to address the potential issues. This field of work, of monitoring structural

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integrity of critical buildings and facilities bears the name of SHM (structural health monitoring).

A structure's condition changes over time and problems can rise as early as construction stages, and its health is subject to change caused by weather and environmental factors, aging and quality of building materials, accidents of natural disasters. Taking into account these kinds of buildings purpose and importance, being able to foretell its evolution and take proactive actions becomes a matter of strict necessity. SHM systems come to address and solve this problem, offering an instrument that can give us an extensive and precise image of a structure's evolution over time.

As a result of the development of new technologies in the field of sensor manufacturing and data acquisition systems in the recent year, many monitoring systems became available on the market. These monitoring systems, however, integrated one or several measurement technologies, but the authors of this paper were not able to find a robust, yet flexible and easily scalable system that would encompass all the technologies available on the market and enable a unitary approach of structural health monitoring.

The previous experience of the authors in implementing data acquisition systems for various types of SHM applications proved the increasing need for such a system, that could be easily configured to match the needs of most of the applications. Therefore, using their knowledge and extensive experience in the field, the authors developed static and dynamic SHM system, called **SIMON**, as a result of a project within Competitiveness Operational Program (COP) 2014-2020.

SIMON stands for *Intelligent multiparameter System for complex and Integrated MONitoring of structures for disaster risk assessment and reduction* and it was the result of a 2 years project that aimed to solve the problem of integrating different technologies and components from different suppliers into a unitary system.

2. SIMON – A complete system for SHM applications

As we previously mentioned, SIMON's goal was to integrate the most used technologies in SHM into a single, robust, flexible and scalable system that could be implemented in various configurations for different types of application. That meant power supplying different types of sensors, enabling time synchronization between different modules of the system, and data acquisition using a single software application and database. Another scope was to build a system that could be deployed starting with the construction phase, for both short-term and long-term monitoring.

Previous experience has shown that there are 5 technologies that are used in most SHM systems, some of them traditional and others developed in more recent years. SIMON manages to include all of these technologies, in configurations that can use one, several or all of them, depending of the application and system requirements. In order to do so, SIMON also contains a special module that ensures communication, synchronization and power supply to all measurement modules, based on PoE Ethernet technology.

Fig. 1. SIMON system configuration

In the following paragraphs, we will present each of these technologies, with their particularities and characteristics, as well as the special modules we use to integrate these measurement technologies.

2.1. MON-3AX - Triaxial accelerometer biaxial precision inclinometer

This type of device combines precision MEMS sensor technology with on-board signal processing technologies and digital remote transmission of measured values. This thing ensures immunity to electromagnetic disturbances and enables long distance data transmission. The module has an IP67 enclosure because it needs to be mounted directly on the structures to be measured and can operate in an extended measurement range.

As its name implies, this module can measure simultaneously acceleration in 3 directions, and inclination in 2 directions and can also provide a temperature measurement. A single system cand include up to 32 units that can be part of SIMON together with other modules and technologies. As a result, MON-3AX can be used in seismic instrumentation, long-term monitoring of bridges, dams, buildings, stadiums, monuments and industrial structures. In the below figure, you can observe a MON-3AX module.

Fig. 2. MON-3AX - Triaxial accelerometer biaxial precision inclinometer

2.2. MON-FO8 - Fiber optic sensor interrogator with Bragg (FBG) networks

Fiber optic sensing is one of the newest technologies used in SHM, that has shown very good results and a high degree of flexibility and other advantages that will be detailed below. MON-FO8 is a fiber optic interrogator that can have 1, 4 or 8 channels and can perform both static and dynamic measurements on fiber optic sensors with BRAGG networks (FBG type). Each measurement channel can measure up to 20 sensors each, depending on the dynamic range assigned to each sensor.

These sensors are very versatile, being able to measure either stress, deformation, temperature, inclination, acceleration, pressure or force. This particularity makes them suitable for a large range of applications and types of structures. Another important advantage is that because the work on optic principle, they are immune to electromagnetic disturbances, can be deployed over long distances and do not need power supply. MON-FO8 has no moving parts, so it is reliable and accurate. In the image below you can see a MON-FO8 module, which has a compact design and offers the possibility of rack-mounting.

Fig. 3. MON-FO8 - Fiber optic sensor interrogator with Bragg (FBG) networks

The module can be power supplied through PoE or from a 12 Vcc external source. As a result of its unique characteristics, this module can be used for bridge, viaduct, tunnel, works of art, energy, oil and gas infrastructure monitoring, laboratory measurements, or aerospace applications.

2.3. MON-VW8 - Measurement module with vibrating wire sensor

Vibrating wire measurement is a traditional technology used in SHM, robust and reliable and could not miss from SIMON structure. MON-VW8 is a vibrating wire module with 8 channels for vibrating chords sensors and 8 corresponding temperature sensors. This module cand be used both with new sensors and existing sensors that are already deployed in the field.

MON-VW8 can be used for long-term monitoring of bridges, tunnels and geotechnical structures, dams, buildings, stadiums, monuments etc...

2.4. MON-EA8 - Measurement module with 8 configurable universal channels

MON-EA8 is a module with universal sensors, with 8 channels, that can perform both static and dynamic measurements. Every of those 8 channels can be configured as a voltage, current, resistance, potentiometer, thermistor, tensometric bridge or LVDT bridge channels. Every sensor can be power supplied through the module and MON-EA8 can be powered through PoE or from an external 12 Vdc/24Vac.

2.5. MON-ME16 - Measurement module with magnetoelastic sensors

MON-ME16 is a module for reading data from sensors using the principle of magneto-elastic measurement. This type of sensor is based on modifications of the magnetic properties of a ferromagnetic material under the influence of the stress to which it’s subjected and of the temperature. Therefore, these sensors are particularly suitable for effort measurement in cables and strand type elements in a non-intrusive manner. The module can be produced in 4, 8, 12 or 16 channels configurations.

This kind of sensors are reliable and accurate as they do not contain moving parts, is resistant to dust, vibration, chemical agents and bad meteorological conditions. As a result, the sensors can surpass the lifetime of the construction, making them perfect for long-term monitoring of cable-stayed bridges, stadiums etc.

2.6. MON-GW - Data acquisition and communication module

As mentioned in the previous chapters, SIMON also includes a special module that makes it possible to integrate all of the technologies mentioned above in a single, unitary system. MON-GW includes configurable hardware and software and realizes communication with the data acquisition modules, allowing their configuration and data processing.

It also provides a synchronization signal, power supply for the other modules, performs primary analysis and filtering of the measured data, as well as their storage. Furthermore, it can facilitate communication with a PC or Server that is running a data acquisition, analysis and storage program, but it can also function independently.

As Fig. 1 shows, MON-GW is the heart of SIMON system, being the link between all the other modules and being indispensable in any configuration.

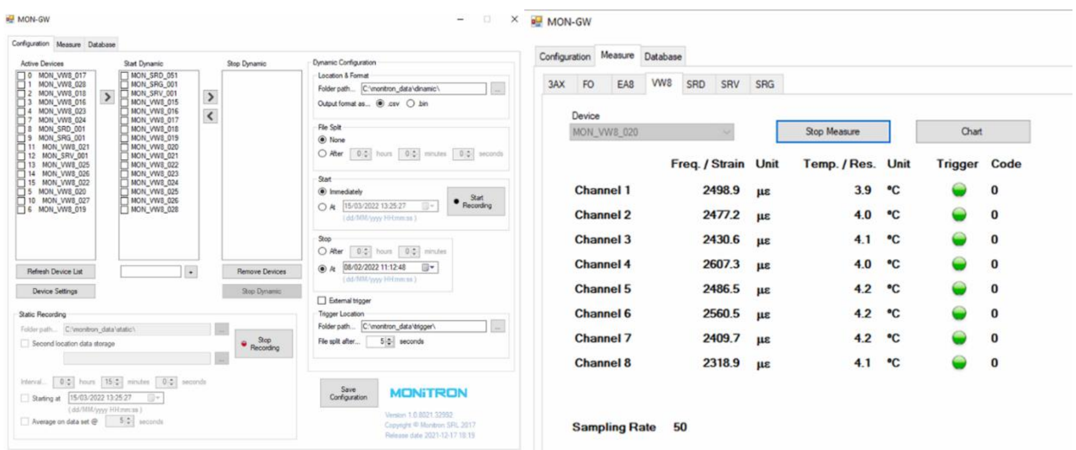

Fig. 4. A general MON-GW configuration screen (left) and a measurement screen for a MON-VW8 unit (right)

3. Application example – Steaua stadium monitoring project

As we all know, Romania was selected to host a number of football matches during the EURO 2020 competition. As preparation for this event, The Romanian authorities had to built 4 new stadiums for hosting official trainings and matches during the competition. One of the stadiums selected for demolition and rebuilding according to modern standards was Steaua Stadium from Bucharest. At this moment, the stadium with a capacity of 31254 seats is completed and fully functional. It has a dimension of 211 x 162, covered grandstands, an underground car park and other facilities.

From a structural point of view, a mixed solution was chosen that uses prefabricated reinforced concrete (steps, “raker beam” beams), monolithic reinforced concrete (pillars, floors, beams, walls, stairs) and a metal structure for the roof.

Taking into account the complexity of the structure, the beneficiary also requested a monitoring system to be installed during construction for long-term monitoring. MONITRON offered a solution based on SIMON system. This was a good opportunity to show our system’s capabilities and advantages, such as scalability, flexibility and reliability.

The system that was deployed in the field consisted of the following:

- 100 vibrating wire sensors, from our partner SMARTEC, mounted on 10 beams of the roof, 10 sensors on each beam;
- 10 laser displacement sensors, from our partner Waycon, each sensor mounted on the top of every of the ten been with vibrating sensor wires;
- 4 wind sensors and 2 snow sensors;

The reading units supplied were also provided by MONITRON, with 13 MON-VW8 vibrating wire reading units, Industrial MiniPC, Poe switches, MON-GW Recorder software for data acquisition and processing.

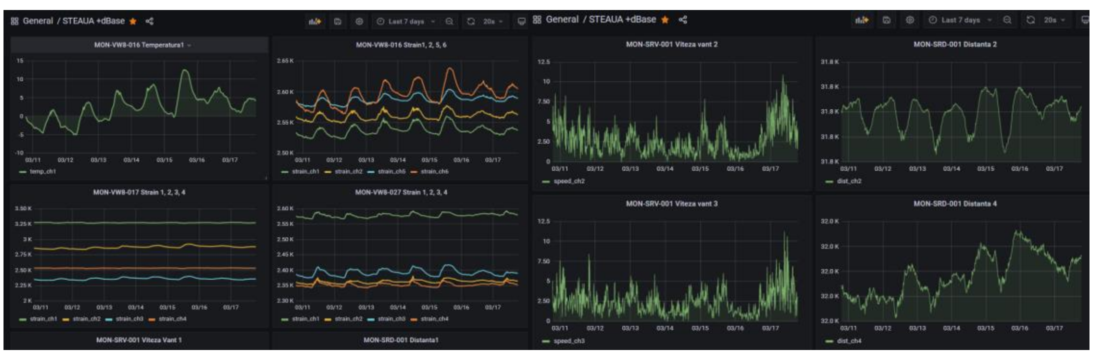

Fig. 5. Seven days evolution for a selection of sensors (left) and for wind and distance sensors (right)

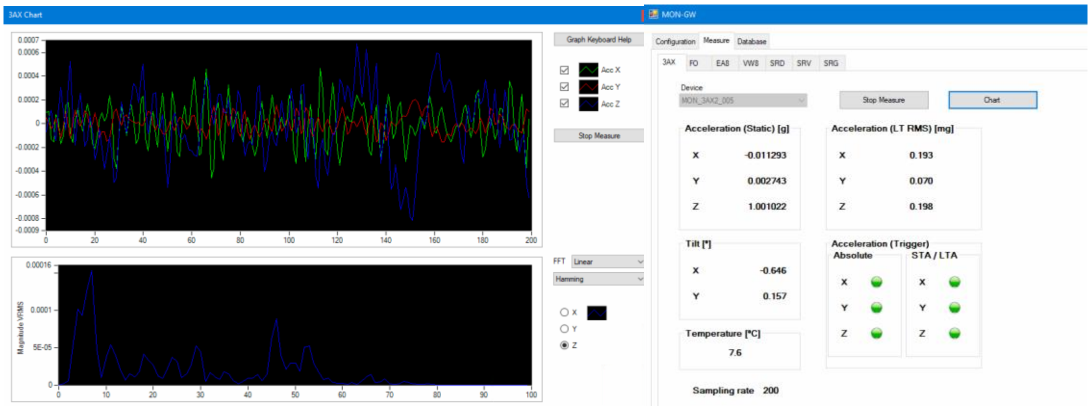

Fig. 6. A screenshot of MON-GW Recorder acceleration waveform received from a MON-3AX unit (left) and with acceleration and inclination values from the same unit

4. Conclusion

Previous experience of the authors has shown that the development of a system that can be configured and adapted to a variety of structures that need monitoring is a complex endeavor. In a continuously developing and changing world, long-time monitoring of structures has become a necessity and because of that, being able to rapidly configure and deliver a suitable system for every application encountered is of great importance.

As it was proved through the projects that already use SIMON as part of their monitoring system, including the example provided above, it has been demonstrated that our system can be a strong and reliable solution for both simple and complex monitoring projects and that the need for such a system in the near future will grow rapidly. Therefore, focusing on further developing the system, regarding both hardware and software aspects is the right direction to follow.

R E F E R E N C E S

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