MEMSCON Newsletter

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Issue 1

Radio Frequency Identification Tags Linked to on Board Micro-Electro-Mechanical Systems in a Wireless, Remote and Intelligent Monitoring and Assessment System for the Maintenance of CONstructed Facilities

MEMSCON Facts:

- Contract No: 036887
- Project total cost: 4.632.430 €
  EC contribution: 3.814.816 €
- Project Start Date: 1/10/2008
  Duration: 36 Months
- Coordinator:

Dr Angelos Amditis

E-mail: A.Amditis@iccs.gr

Institute of Communication and Computer Systems (ICCS), Athens, Greece

Inside this issue:

Wireless Technology for Seismic Protection of Buildings

Rapid advances in sensing and data transmission techniques, as Radio Frequency Identification (RFID) technology, Micro-Electro-Mechanical Systems (MEMS), lower power wireless networking and in computation give hopes for a new generation of small,

inexpensive, networked sensors that can be distributed on civil and building structures to provide accurate, quantitative information on the structure's physical state while in service. This information can be used to assess the structural condition of the monitored facility and aid decision making on rehabilitation so that safety can be attained and rehabilitation costs can be reduced.

The aim in project MEMSCON is to develop MEMS)- based sensors for construction monitoring and to integrate them with a Decision-Support-System (DSS) that will use the information from the above sensors to aid decisions on proactive rehabilitation and rehabilitation after earthquake damage in reinforced concrete (r.c.) buildings.

This work is co-funded by the European Commission under Theme 4—Nanosciences, Nanotechnologies, Materials and New Production Technologies of the 7th Framework Programme.

This first newsletter presents the project objectives and expected impact and an outline of the MEMS-based sensors and DSS under development.

MEMSCON Newsletters are sent to all members of the MEMSCON Mailing List composed of stakeholders including building facility owners and managers, Construction companies, Building maintenance Departments of Local and Federal government and others. Anyone interested is invited to register in the MEMSCON Mailing List (see Contact Section).

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Towards Wireless Intelligent Structures

Today, the appraisal of the seismic damage is almost exclusively based on visual inspection. Measuring quantitatively the response of buildings during and after an earthquake, in terms of acceleration of strain, is today an easy task. However, the owners are somehow reluctant to install permanent sensing systems, both for the high costs of these devices and for the difficulty of interpreting the data.

To overcome these limitations, MEMCON project aims

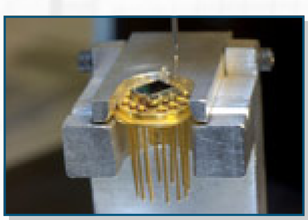
a) To produce small size sensing node, **integrating MEMS-based sensors** and an **RFID tag** in a single package that will be attached to reinforcedconcrete (r.c.) buildings for life cycle measurements of **acceleration** or **strain** that will be transmitted to a remote base station using a wireless interface. These nodes will lead to an economically sustainable industrial deployment.

b) To **develop** an automatic software to process the measurements and define the condition state. This is the **Decision-Support-System (DSS)**, which particularly aims to the proactive rehabilitation and rehabilitation after earthquake damage in r.c. buildings. This DSS will accept input from the sensors in order to assess the structural condition of the monitored building and to select optimal remedial measures and

c) To **evaluate experimentally and in the field an integrated package** of the Wireless Sensor Networks and the Decision-Support-System.

Managing Earthquake Risk

MEMSCON promotes "Proactive Condition-Based Maintenance" of buildings



The above described integrated package for building monitoring and assessment will promote 'Proactive Condition-Based Maintenance' which is based on measurements aimed at an early detection of degradation, thereby allowing degradation to be eliminated or at least controlled prior to significant physical deterioration. The result is a significant decrease in maintenance cost, because problems are less expensive to fix when they are first developing, and an increase in building safety.

The impact on safety will be more pronounced in the case of an earthquake where it is essential to have an accurate and quick assessment of the building structural condition for several reasons:

(a) dissemination of information to emergency response officials on building collapses within minutes after the occurrence of the earthquake can result in lives saved and prudent allocation of resources and

(b) quick and accurate estimates of the level of damage can be used to indicate loss of function and help officials decide whether the school, hospital, etc., should be evacuated or remain in service. Often such information is delayed due to weather conditions, lack of daylight, inappropriate survey equipment or lack of access to the site due to terrain obstacles.

The Monitoring Devices

Sensing and wireless communication will take place at specified time intervals as needed. To assess the progress of ageing, strain measurements will be taken regularly every few months and on demand.

The measurement of acceleration will only take place during earthquakes.

As a constant monitoring of the acceleration requires too much power most of acceleration sensor nodes will be kept in a low power mode until they receive a “wake up call”.

The “wake up call” will be generated by selected accelerometers within the building: as soon as a certain acceleration threshold is passed at these nodes the entire network will be activated.

What are the drivers for the MEMSCON project?

Compactness and low cost is the main driver within MEMSCON to use MEMS-based sensors. Various MEMS-based accelerometers are commercially available on the market, since a few years also as 3D accelerometers. These sensors have been developed mainly for the consumer market and automotive applications. Although some sensors of the latest generation of of-the-shelf sensors are able to fulfill some of the requirements for the MEMSCON system, **the low power consumption is the critical point that cannot be satisfied with these sensors**.

What are the MEMS-based accelerometers and Strains sensors under Development?

There are two different trends in MEMS technology: monolithic integration and hybrid integration. Monolithic integration allows the fabrication of the MEMS element on the same die with the signal conditioning circuitry whereas hybrid integration uses the system in package approach. By taking full advantage of batch processing, both solutions allow the realization of cost effective sensors with improved performance and reliability. In view of the limited time window in this project for tag prototyping, and the level of system integration required for the MEMSCON system, the hybrid approach has been chosen and the MEMS sensors and the electronics will be fabricated separately. Critical electronic functions will be integrated on an ASIC and assembled close together with the MEMS in one package.

Each accelerometer will be capable of measuring accelerations of up to +/- 2g, in 3 dimensions, with an accuracy of few mg’s. In order to achieve the requested life time the accelerometer and the related electronics must be

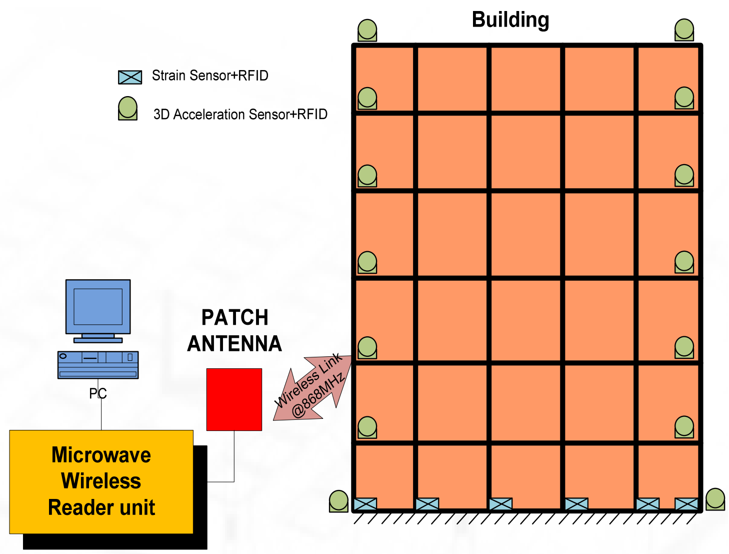


Figure 1. Hardware (Sensors, Data Collection Hardware and Wireless Communication) in the Monitoring System under Development.

“Monolithic Integration and Hybrid Integration result in improved sensor performance and reliability as well as reduced sensor cost in the case of mass-volume production.”

The Monitoring Devices (cont)

Only one ASIC need to be designed that can be used for both MEMS sensors, further reducing the cost of each sensor

designed from the beginning for low power consumption

Strain gauges provide the technical basis for common systems to measure strains in the monitored sections of constructed facilities. While metallic foil strain gauges are widely used, strain gauges can also be constructed from semiconductor materials. Having the strain gauge fabricated in semiconductor material offer the same processing advantages as for the 3D accelerometer. Moreover, this also allows for choosing the sensing principle and matching it with the accelerometer. By doing so, only one ASIC need to be designed that can be used for both MEMS sensors, further reducing the cost of each sensor.

What is our challenge? Our main challenge in the strain sensor is the combination of a high range: ±30’000µe with a high accuracy: 10µe. The advantage of semiconductor material is the possibility of fabricating a sensor with high precision and high accuracy. However, semiconductor materials are brittle and therefore not suited to experience large strain. With the freedom that MEMS processing offers, this problem can be overcome through clever designs and the required specification met.

The goal of the strain sensor will be to measure the strain in the rebars of the reinforced concrete column of the building. Hence, the installation of the sensors will be made prior to pouring of the concrete. This poses some extra difficulties in the packaging of the sensor because of the harsh environment created by fresh concrete (pH of 14). In addition to this constrain, the package also has to be flexible and stretchable so that it doesn’t interfere with the strain measurements.

Finally, due to the fact that the strain sensor will be embedded in concrete, the sensor will be designed into 2 separate packages so that one package, containing the battery and the antenna, can be placed outside of the column for improved antenna transmission/reception and to be able to change the battery. The package embedded in the concrete will be attached to the rebars of the concrete column. The long term reliability of this assembly is critical since it will not be accessible after the construction of the building and therefore must have an extended lifetime (similar as the building lifetime).

The Decision Support System

The DSS

The general architecture of the DSS under development can be seen in Figure 2 below. It includes an Expert System that is connected to the Knowledge Base and the Sensor, History and External Data databases and Modules 1, 2 and 3.

How are strain measurements evaluated ?

In Module 1 input on strain in the monitored, critical, locations of a r.c. building will be processed to derive stresses and moments which will be compared to limit values in order to determine the structural adequacy of these critical cross-sections. Based on this and on how loads are distributed to the different members the global structural condition of the building and the possible need for proactive maintenance will be determined.

How are acceleration measurements evaluated ?

In Module 2 input from the acceleration sensors in a r.c. building during an earthquake will be processed to estimate:

1. Areas where the design ground acceleration has been exceeded;
2. the maximum displacements derived after double integration in respect to time of the monitored acceleration time history that will be compared to the max. design elastic displacements;
3. damage and possible need for rehabilitation.

What do we do with the derived Information on the Structural condition ?

Module 3 will accept input on structural damage from Modules 1 and 2 based on which it will identify the feasible options and the resulting costs for proactive rehabilitation and seismic upgrading respectively.

How can we reduce the required number of strain Sensors ?

To directly assess the axial force and the bending moments in a cross-section, strain sensors are required at

> **"Based on sensors response, the global structural condition of the building and the possible need for proactive maintenance will be determined"**

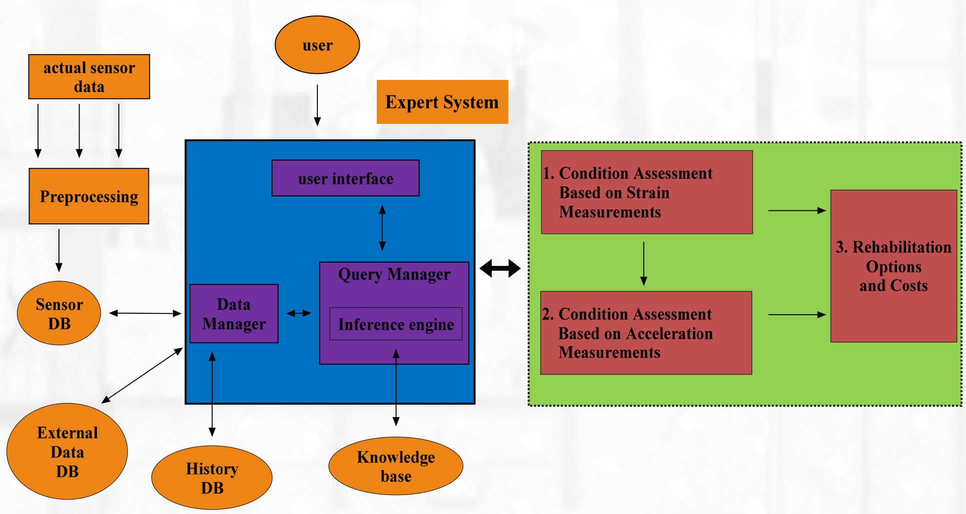
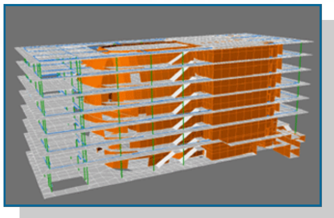


Figure 2. General Architecture of the Software in the DSS under Development

The Decision Support System (cont)



> **The no. of required sensors can be dramatically reduced when instead of aiming at a direct assessment of the internal forces in each member; some critical global parameters of the overall stress condition are being sought**

the four corners of the cross-section at the extremes of each structural member. Thus, a total of 8 sensors are required for each member, such as beam, column and shear wall.
Therefore, for a structural system consisting of 'n' linear members, the required no. of sensors will be 8n .
As an example, for the direct assessment of the internal forces in the members of a 6-story building with plan dimensions of 15x15 square meters, to which correspond about 16 columns and 24 beams per story, the total no. of members being n=6 (16+24)=240, the required no. of sensors will be 8x240=1920.
The no. of required sensors can be dramatically reduced when instead of aiming at a direct assessment of the internal forces in each member; some critical global parameters of the overall stress condition are being sought. Then, the internal forces in each structural member as well as their structural adequacy can be assessed through a finite element programme that will accept as input the measured values of the above critical parameters.
Under operating conditions the most common reason for changes in the internal forces during the building life-span is differential settlement between foundations on cohesive soils subjected to consolidation. It is not possible to measure the absolute value of settlements through strain sensors. However, it is possible to estimate the support reactions at the columns' bottom cross-sections on the foundations, at which locations the strain sensors will only be placed (see Fig. 1). Thus, in the case of 16 columns of the 6 story building in the previous example, the no. of the required strain sensors is reduced to 4x16=64 sensors. The changes in the values of the support reactions that will be estimated in sequential periodic measurements (say, once every 4 months) compared to the values measured in the initial condition of the building will constitute the input for the finite element analysis. The sum of the measured axial forces on the columns equals the sum of the active vertical loads on the structure. The vertical loads that will be applied on the members in the model will be equal to the initial design loads multiplied by the ratio of the total active loads to the total initial design loads.

What happens if an Earthquake occurs?

The assessment of the internal forces and the strength adequacy of the structural members after an earthquake will be performed through a non-linear, dynamic, finite

The Decision Support System (cont)

element method of analysis taking as input the recorded time history of the accelerations during the seismic event. Considering the floor slabs as diaphragms undistorted at their plane, for each story, required are the time histories of accelerations in 2 directions perpendicular to each other and 1 rotational acceleration around the vertical axis. With 3D acceleration sensors that will provide acceleration measurements in 3 vertical axis, since there will be no measurement of torsion, use will be made of two parallel accelerometers at the ends of the slab to be able to derive the torsion and the other required acceleration measurements. Two such accelerometers will also be placed at the foundation level . Thus, for the 6 story building of the previous example, the no. of required acceleration sensors will be 2 (6+1)=14.

Dissemination

Most important conferences relevant to MEMSCON research area:

2nd International Conference on Smart Materials and Nanotechnology in Engineering (SMN2009)
8-11 July 2009
Weihai, Shandong, China
http://smart-nano.org/smn2009/en/frame.htm

4th International Conference on Structural Health Monitoring of Intelligent Infrastructure (SHMII-4 2009)
22-24 July 2009
Zurich, Switzerland
http://www.ishmii.org/News/SHMII4.html

INTERNATIONAL CONFERENCE ON WIRELESS COMMUNICATION AND SENSOR COMPUTING
2-4 January 2010
Chennai, India
http://www.ssnicwcsc2010.in:8040/index2.jsp

SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring
7-11 March 2010
San Diego, California, USA
http://spie.org/x12228.xml

European Workshop on Structural Health Monitoring (EWSHM-2010)
29 June - 2 July 2010
Sorrento, Naples - Grand Hotel Vesuvio - Italy
http://structure.stanford.edu/workshop/past/announcement_ewshm2010_final.pdf

9th U.S. Nat'l & 10th Canadian Conf. on EQ Eng.: Reaching Beyond Borders
23-29 August 2010
Toronto - Westin Harbour Castle Hotel - Canada
http://www.2010eqconf.org

14th European Conference on Earthquake Engineering
30 August - 3 September 2010
Skopje-Ohrid, FYROM
http://www.eaee.boun.edu.tr/ecee/skopje2008.pdf

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MEMSCON Contact Details

Project Co-ordinator:

Dr Angelos Amditis
Research Associate Professor
Institute of Communication and Computer Systems
A.Amditis@iccs.gr

Technical Manager:

Dr Matthaios Bimpas
Institute of Communication and Computer Systems
mbibas@iccs.gr

Dissemination Manager

Professor Daniele Zonta
University of Trento
Daniele.Zonta@ing.unitn.it

Scientific Officer:

Dr. Ir. Dominique Planchon
Dominique.PLANCHON@ec.europa.eu
European Commission
Research Directorate - General
Directorate G - Industrial technologies
Products, Processes, Organisations

For further Information:

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