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Intelligent Infrastructures Systems for Sustainable Urban Environment

Extensive research is now under way around the world to develop advanced technologies to enhance the performances of infrastructure systems. While these technological advances are incremental in nature, they will eventually lead to structures which are distinctly different from the actual infrastructure systems. These new structures will be therefore capable of Structural Health Monitoring (SHM), involving applications of electronics and smart materials, aiming to assist engineers in realizing the full benefits of structural health monitoring.

Keywords: *intelligent infrastructures, shape memory alloys, vibration dampers*

1. Introduction

An efficient infrastructure system is essential to every country's productivity, security, and quality of life. Smart structures technology offers tremendous opportunities for improving the performance, quality and environmental impact of products in many industrial sectors. Basic research and development in smart structures and designer materials have shown great potential for enhancing the functionality, serviceability, security and increased lifespan of civil infrastructure systems. New construction or the intelligent renewal of ageing and deteriorating civil infrastructure systems include efficient and innovative use of high-performance and smart materials, sensors and actuators, along with intelligent mechanical and structural systems. High-performance designer materials, in particular, require new methods of computational materials science.

The smooth functioning of a modern large city depends on the reliability of many inter-linked systems which all have to be designed, constructed, monitored and maintained over a long period of time. Among these systems is the large number of structures, including buildings and bridges, which often comprise the major part of the infrastructure investment. In the present paper we are presenting a solution regarding the development of a new generation monitoring system of infrastructures, which will better support the development of sustainable urban systems, consisting in the use of Shape Memory Alloys for designing an Intelligent Vibration Control System IVCS.

Applying these future solutions, the infrastructure systems will not only last longer but will have far lower maintenance demands. They will be able to be modified to accommodate changes in exploitation or function more quickly and in a far less intrusive manner than current technology allows.

2. Analysis.

The key challenge of this solution is to bring the current fundamental breakthroughs on the level of materials, IT, electronics and control to the level of industrial use in integrated applications. To be able to realize this, the smart systems should not any longer be considered as a product add-on. The material and smart system design process must become part of the complete, integrated, product creation process, requiring the development of an adapted simulation-based Computer Aided Engineering methodology.

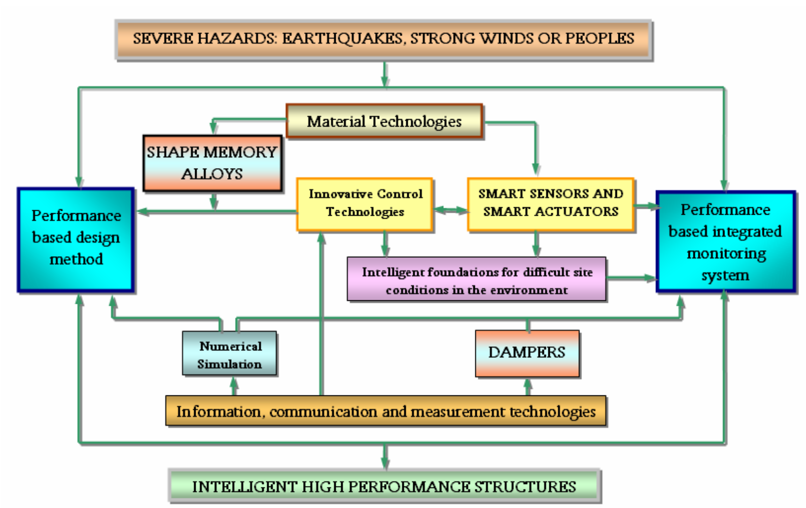

Figure 1. Functioning principle of the IVCS

The core idea is to develop such modeling framework for designing macro-scale active noise and vibration control applications based on the integration of intelligent, high-performing, material systems. This requires the development of modeling capabilities for the intelligent material systems and sensor / actuator components, for the control systems as well as for their integration in system-level virtual prototyping models, enabling the evaluation of performance as well as reliability and cost aspects.

Making this next step in smart systems goes beyond the technological developments. The key requirement is that the various domain specialists on the level of materials, electronics, control systems, design simulation, dynamics, noise, vibration etc, step outside their niche expertise domain and get fully acquainted with the multidisciplinary aspects related to the integration of all these components in industrial applications. Without this, smart structures will remain an academic topic. As such integrated knowledge is at present not available with product and subsystem designers, a multidisciplinary training program is needed and will be developed. A dedicated training course program, a schedule of research exchanges and a well-structured training-through-research program are the basic elements.

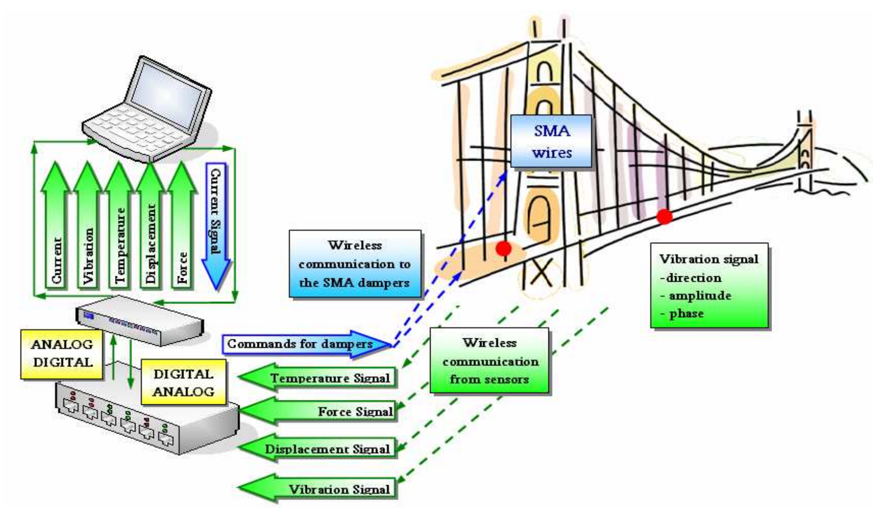

Figure 1. Functional scheme of the IVCS applied to a bridge infrastructure

Based on the above observations, future infrastructures may be expected to possess the following salient features:

1. durable in the sense that they are highly resistant to environmental degradation over time;
2. intelligent, in the sense that they are able to continuously monitor their own state of health and activate the control devices when necessary to minimize the effects of extreme loadings (e.g. strong winds, earthquakes, fires and land slides) to ensure desirable structural performance; and
3. performance-oriented, in the sense that they are designed and constructed

to satisfy specific whole-life system-level performance objectives.

Thus, we aim to design, model, develop and validate an intelligent system based on a network of devices that can be used for simultaneous damping of structural vibrations and detection of damage in infrastructures systems (buildings, bridges, etc.). The IVCS will introduce both technological and methodological breakthroughs while addressing some of the main issues of "distributed measurement systems". In order to achieve this, we will develop a real-time intelligent vibration control system using innovative semi-active and active control devices, i.e., a structural condition assessing, controlling and reduction system for infrastructure. We propose to monitor the static and dynamic motions of the infrastructure system by using acceleration, GPS, and sensors, and develop real-time algorithms for data analysis and damage detection.

In particular, the Intelligent Vibration Control System incorporates the following advances:

- the vibrations of the structure are used as energy source for the actuators, sensors and other electrical loads. The emphasis is put on highly efficient energy harvesting, using state of the art technologies. This induces significant space and weight savings compared with various existing smart systems;

- the sensors data collection is managed through a smart RF network, gathered in a database;

- based on the signals gathered from the sensoring network regarding the vibrations (type, amplitude and prolongation direction), along with signals regarding the SMA actuators (temperature, force and displacement), the intelligent system will be able to decide what are the appropriate commands to be executed by the dampers;

- several monitoring strategies are addressed aiming at defining new condition-based maintenance programmes and inspection procedures;

- the robustness of the system is thoroughly investigated, including the structural integrity of the device itself and of the interface between the device and the support made of composite materials;

- in terms of damage evolution, coupling both vibration damping and real-time monitoring results in a synergetic mechanism between delaying the occurrence of critical damage and accelerating its detection.

Among the IVCS benefits, we can highlight the definition of custom-tailored maintenance program, the increment of the lifetime of the parts and of the entire system or the increment of the reliability of composite parts.

All these elements help reducing the total cost while being a major contribution to the infrastructure safety and reliability.

For the development of third-generation structures, the use of more sophisticated design methods demand a better understanding of the natures and effects of severe hazards including strong winds, earthquakes and fires. Here, the use of advanced computational tools, in conjunction with full-scale measurements (e.g. Xu and Zhan), should be particularly useful. For example, the development and application of computational fluid dynamics models to predict wind loading has received a great deal of recent attention and has the promise of accurate predictions of wind loading and wind-structure interactions. In such studies, issues of special importance to large urban centers such as the close spacing of buildings and the boundary wind structures over an urban area should be given particular attention.

4. Conclusion

It may be envisaged that in the era of third-generation structures, a structure will be designed using the performance-based approach employing a numerical simulation tool which can capably predict the behavior of the structure including the contributions of control devices, the interaction between the monitoring and control mechanisms, and deterioration with time. The structure will be constructed with a powerful computer (i.e. the brain of the structure) on which an Internet-GIS based monitoring system is installed and lined to smart sensors and control devices. The behavior of the structure, as monitored by the sensors, will be regularly compared with the predictions of the numerical model based on loadings provided by the sensors, so the computer model is continuously improved to achieve maximum accuracy. Over the life span of the structure, the state of the structure can be accurately assessed by combining the sensor inputs and the numerical model. When extreme loading conditions arise, the monitoring system will activate the control devices based on sensor inputs to protect the structure from failure. Afterwards, the monitoring system will determine the remaining life of the structure.

It will take some time before third-generation structures as envisaged above can be realized but it is hoped that in the not so distant future, the idea of third-generation structures can be implemented and studied in a number of laboratory-scale structures. Such model third-generation structures can be tested to demonstrate and assess their performance. In the transition period to the full realization of third-generation structures, the associated technological developments can be expected to have a great impact on the performance enhancement of second-generation structures. For example, vibration control and health monitoring technologies can be implemented in existing structures for retrofit and monitoring purposes as well as in new third-generation structures. In this sense, third-generation structures and the associated technological advances offer great benefits for the sustainable development of urban systems.

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