Structural Monitoring Handbook - stating the defining direction

Adrian T.G. Radulescu, Gheorghe M.T. Radulescu, Romania and Vassilis Gikas, Greece

Key words: conventional techniques, Structural Monitoring Handbook, the time behavior monitoring

SUMMARY

The emergence of new methods and technologies for structural monitoring has occurred slowly, until two decades ago, while developing new methods, tools and also conventional techniques, nowadays the information explode, appearing practically endless combinations in shaping the time behavior monitoring of an objective. In this context, the authors have considered the need for a monitoring handbook, which is to rank the available information, to provide complete and updated data on the available tools and methods, classified on the data recording system: static and kinematic, and secondly to provide solutions according to the monitored structure category. The purpose of this handbook is to provide structural operators, regulatory authorities and industry consultants with guidelines relating to planning and implementation of structural monitoring strategies. The handbook includes general guidelines and principles for structural monitoring, and presents suggestions for procedures and methodologies that are based on Romania and EU legislation, with the aim of establishing and promoting a uniform best practice code for the entire for the structural in time behavior process in static and cinematic regimen. The Initial Structure Evaluation process is the first level of risk assessment for the established inventory of structures. The Initial Structure Evaluation applies established, weighted criteria to gathered existing information and information from one structure visit. Data management and analysis are crucial to understanding the behavior of a monitored structure, for detecting unsafe developments, and for determining the performance of the instrument systems. The major aspects of the instrumentation planning process are data management, engineering analysis, and formal reporting. It is a continuous process from data collection through reporting. At every step of the analysis, the evaluator should be conscious of the potential for invalid data and the improper use of the calculations, so that incorrect interpretations are not made. The selection of a measurement technique to be developed in the framework of a research project like STRUCTURAL MONITORING must pursue two main objectives: a new system has to respond to a real need of the end-users, it should constitute an innovative approach in the domain of metrology and present some originality compared to the work of other research laboratories active in the same field. This paper presents the general aspects of this approach, which is extremely useful in terms of achieving increasingly challenging constructive performance, both for designers and for operators, builders or geodesists. This paper presents the general aspects of Structural Monitoring, which is extremely useful in terms of achieving increasingly challenging constructive performance, both for designers and for operators, builders or geodesists.

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1. INTRODUCTION

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Preparation of this handbook was one of the central objectives of the **STRUCTURAL MONITORING** project. Background research for the handbook included comprehensive reviews of relevant literature and analysis of various issues relating to the structural monitoring process, including Romanian and international legislation and best practice procedures, risk assessment, procedures for evaluating the long-term behaviour of constructions and various structures; hydrological and geological modelling; and post construtions monitoring strategies. that this latter goal to be practically impossible to fulfill. Through this work wee proposed, firstly, to fill this informational gap, to seek and know the most relevant achievements in the field. For it had to reconsider the monitoring activity of the land and constructions, launching the concept of monitoring in three segments (static, quasistatic-quasidynamic, dynamic), relative to the structure response speed to stress. Thus appeared the concept of kinematic topography-surveying, as a new chapter of engineering surveying, which the practically continues the time monitoring of land and constructions.

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2. OBJECTIVES AND SCOPE OF THIS HANDBOOK

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The purpose of this handbook is to provide structural operators, regulatory authorities and industry consultants with guidelines relating to planning and implementation of structural monitoring strategies. Time behavior monitoring of the constructions and land as defined here covers a range of activities and procedures, relating to and following the point at which production finally ceases permanently, from decommissioning of plant and relinquishment of title, through to implementation and ongoing monitoring of structural rehabilitation programs. For some activities, legislation defines objectives and provides an operational framework, while in practice, decisions are typically made using a combination of best practice and previous experience. The handbook includes general guidelines and principles for structural monitoring, and presents suggestions for procedures and methodologies that are based on Romania and EU legislation, with the aim of establishing and promoting a uniform best practice code for the entire for the structural in time behavior process in static and cinematic regimen. Although the purpose of the handbook is to provide general guidelines, each case needs to be assessed on an individual basis, taking into consideration such diverse factors as category of structures,constructions method, nature of foundation soil and surrounding environment.

As a general principle however, the primary stated objective of successful structural monitoring is to ensure that the form construction site is restored to a condition where it no longer represents any kind of environmental, health or safety risk. To achieve this objective, it is also desirable that monitoring planning is seen as an integral part of the pre/in/post constrution process from its inception.

The handbook has to be structured such that the introductory section provides a background to the structural monitoring process, including the overall life-cycle perspective and environmental context of the construction execution, together with a brief review of the diversity and significance of surveying activities in UE. Then an overview of general objectives and principles relating to concept of Structural monitoring will follow with a more detailed discussion of legal and environmental issues. Nevertheless, the intention is not to provide an exhaustive guide to the entire legislative framework, but to provide the relevant regulations for Structural monitoring.

3. AN OVERVIEW OF STRUCTURAL MONITORING AND THE CONSTRUCTIONS LIFE-CYCLE

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Security of the civil engineering works requires regular monitoring of the structures. The current methods are often difficult applications, the resulting complexity, dependency from the condition of the atmosphere, and also the costs, limiting the applicability of these measurements. Special attention is therefore focussed on maintaining them in a serviceable condition. The problem is quite complicate as it is function of their age, variety of structural types, different processes of deterioration and increasing volume and composition of traffic. From this viewpoint, surveillance and monitoring have already become a widely used standard (5). The aim of these activities is first of all to detect the deterioration process already in its initiation phase and to investigate and identify the causes of deterioration. Secondly, by monitoring the progress of deterioration on the different parts of the structure it is possible to give an input for actions aiming at keeping the safety and functionality of the structure within acceptable limits by performing adequate repair actions. Instrumental monitoring is gaining more and more attention as a convenient tool to follow, on a long-term scale, the global performance or the local variations of relevant properties of structures. Mostly developed in the last 10-15 years, this type of approach even not common practice, has been and is used on both new and existing structures to keep under control structures of strategic importance or very deteriorated structures whose critical conditions may require continuous attention.

4. INITIAL STRUCTURES EVALUATION

The Initial Structure Evaluation process is the first level of risk assessment for the established inventory of structures. The Initial Structure Evaluation applies established, weighted criteria to gathered existing information and information from one structure visit. The Initial Structure Evaluation will result in the subdivision of structures into five risk assessment structure groups. The Initial Structure Evaluation process is begun with three forms of information being available. The first form of information is the list of all roadway structures apparently overlying abandoned underground mines. The second form is the Structure Visit Form and all information gathered in its completion. The third form is the Initial Structure Evaluation Criteria provided in this section.

5. DATA MANAGEMENT

Data management and analysis (17) are crucial to understanding the behavior of a monitored structure, for detecting unsafe developments, and for determining the performance of the instrument systems. The major aspects of the instrumentation planning process are data management, engineering analysis, and formal reporting. A plan for the management and analysis of data should be in place before the instruments are installed. The plan should indicate the frequency of data collection, the extent and timeliness of processing, the level of analysis, the reporting requirements for in-house engineers and reviewing authorities, and the people responsible for accomplishing each of these tasks. The management of data consists of data collection, reduction and processing, and presentation (17).

a. Data collection. Data collection should begin with a well-defined established schedule. The schedule is dependent on project-specific requirements. The requirements are dependent upon instrument characteristics, site conditions, construction activity, or the occurrence of unusual events.

The schedule should be updated whenever these conditions or instrument readings indicate the need. Data collection procedures should adhere to the following guidelines:

Personnel consistency.

1. Instrument consistency.
2. Multiple readings.
3. Coordination of instrument readings.
4. Data records.
5. Data entry.
6. Communication.
7. Warning of unusual conditions. Readings that exceed established threshold levels should be reported immediately.
8. Special considerations of automated data collection.

b. Data reduction and processing. Data processing and reduction consists of converting the raw field data into meaningful engineering values necessary for graphical presentation, analysis, and interpretation. Several calibration constants may be needed to convert the field readings to engineering values. In the past, these conversions were performed by hand, but currently can and should be performed by computers to eliminate conversion errors. Where possible, initial and preliminary reduction and processing of instrumentation data should be accomplished in the field, where anomalous readings, errors, or malfunctioning instruments can be readily identified and/or corrected.

1. Timeliness of data reduction and processing.
2. Expeditious transfer of instrumentation readings from the project site to the reducing/processing/reviewing office is essential in timely data management.
3. Error checking. Checking for errors in instrumentation data should be accomplished at each level of collection and processing (from reading of instruments in the field to final interpretation of the instrumentation data).
4. Reduction and processing methods. Simple computer programs should be used to expedite data reduction.

c. Data presentation. Numerically tabulated data are not conducive to detecting trends, evaluating unanticipated behavior, and comparison with design values. Plots of the data are needed to provide visual comparisons between actual and predicted behavior, a visual means to detect data acquisition errors, to determine trends or cyclic effects, to compare behavior with other instruments, to predict future behavior, and to determine instrumentation maintenance requirement needs. Plotting enables data to be compared readily with events that cause changes in the data, such as construction activities and environmental changes. Plotting also provides a visual means to evaluate unanticipated behavior, and to determine the effectiveness of remedial correction.

1. Types of plots.

(a) Time history plot.

(b) Positional plot. Positional plots show a change in parameter (water level, temperature, deflection, etc.)

(c) Other plots.

2. Guidelines for plotting. Some guidelines for plotting follow:

(a) Appropriate scale should be chosen for the analysis.

(b) Standardize the graph formats and scales for all the projects or features as much as possible to minimize confusion and effort of interpretation.

(c) Location and cross-sectional sketches should be included on the graph to orient the reader to the subject area.

(d) Multiple graphs should be used to explain a situation by showing related conditions.
(e) If appropriate, the predicted behavior and/or limits of safety values should be shown along with the actual monitored behavior.
(f) Significant influences of the measurements should be noted (i.e., construction activities, reservoir level on piezometer level plots and temperature on expansion/contraction plots).

6. ENGINEERING ANALYSIS

Data analysis is the interpretation and evaluation of the data as affected by various conditions(17). It is a continuous process from data collection through reporting. At every step of the analysis, the evaluator should be conscious of the potential for invalid data and the improper use of the calculations, so that incorrect interpretations are not made. Proper analysis will address two basic aspects of dam safety monitoring: the performance of the instrument system, and the performance of the structure or feature that is being monitored.
a. Timeliness of data. The field reading should be compared to the previous data set as it is recorded in the field. Data should be entered into the computer by electronic transfer or immediately upon returning to the office.
b. Analysis techniques. An analytical technique can be considered the viewing of the current information in the context of past experience. It should also consider the predicted behavior of the monitored feature. The review and analysis personnel should consider the following techniques when analyzing the data.

1. Compare current data with the most recent data set to detect anomalies, discernible short-term behavioral changes, and instrument malfunctions.
2. Compare the current data point with historical performance over a significant period of time to ascertain consistency of instrument performance for the monitored feature.
3. Compare current data point with the initial reading for that point to determine the magnitude of change over time.
4. Compare trends of behavior over time with trends predicted during design, with values relating to calculated factors of safety, and/or with any other predicted behavior.
5. Compare the results of one instrument system with those of complementary systems to confirm or deny an implied physical change (e.g., consolidation settlements with dissipation of pore water pressure, pore water pressures with functioning of drains).
6. Use statistical analyses to assess the performance of instruments. Automated systems can acquire a large quantity of data which is conducive to calculating standard deviations and variance of instrument response. This is also helpful in determining calibration frequency.

c. Outcome of data analysis. There are many outcomes of data analysis. The appropriate personnel should consider the following:

1. Determine when to test, calibrate, or abandon instruments.
2. Determine if the schedule of observation should be altered.
3. Reevaluate which areas of the project require priority attention.
4. Determine the need for further study (slope stability, seepage, and other structural performance analysis).
5. Confirm or refute previous studies.
6. Prepare the processed data for formal presentation and develop the engineering position that will be reported.

d. Pitfalls to avoid. The following are some data pitfalls to avoid:

1. Lack of data comparison in the field resulting in invalid data.
2. Delaying data entry, analysis of processed data, and the dissemination of information to involved offices.
3. Assuming data are valid and calculations were executed properly. Software calculation and calibration factors should be periodically checked.
4. Assuming that change in data is reason for concern. Instrument may be appropriately responding to a condition.
5. Assuming no change is satisfactory. Instrument may not be operating.
6. Failing to recognize or incorporate all factors that influence the data (e.g., seasonal temperature changes affecting structural movement, temperature, rainfall, reservoir level values).
7. Assuming contour plots are accurate. Those plots developed by automation or computer software should not be used without a careful review by an experienced geotechnical engineer or geologist who should be thoroughly familiar with the software.

6. SELECTION OF THE SENSING TECHNOLOGY

The selection of a measurement technique to be developed in the framework of a research project like STRUCTURAL MONITORING must pursue two main objectives(6):

1. a new system has to respond to a real need of the end-users,
2. it should constitute an innovative approach in the domain of metrology and present some originality compared to the work of other research laboratories active in the same field.

From the point of view of the end-users seen that a real need exists for short and long gage-length sensors based on fiber optics. These techniques offer the advantage of a small size, insensitivity to electromagnetic fields, currents, corrosion and in some cases temperature variations. Furthermore, optical fibers can be used at the same time as sensors and information carriers, reducing the complexity of the system and potentially allowing the multiplexing of a great number of sensors on a reduced number of transmission lines. Fiber optic deformation sensors, the optical equivalent of rockmeters and inductive sensors, have attracted considerable research interest at the beginning of fiber optic sensor history, especially in the interferometric configuration. Michelson and Mach-Zehnder interferometers with coherent sources (typically gas and semiconductor lasers) were used in the first demonstrations of fiber sensing. Other techniques for deformation sensing rely on micro-bending to encode the deformation in a change of the transmitted or reflected intensity. Some of these techniques have turned into industrial applications.

Requirements

The requirements that a deformation sensor for short (but not dynamic) and long-term monitoring should meet are examined in the next few paragraphs. Low-coherence interferometry in singlemode optical fiber sensors responds to all these requirements:

1 Deformation sensing

A deformation sensor has to measure the distance variation between two given points fixed to the structure.

2 Sensor length

Because of the great variety of structures encountered in civil engineering it is impossible to find a standard sensor length that fits all applications. An all-purpose sensor should allow measurements over length from a few centimeters to a hundred meters and more. The active region can sometimes be up to a few kilometers away from the reading unit.

3 Resolution and precision

The resolution requirements also greatly vary with the application. If the sensors are considered as replacement of conventional techniques like dial gages, it is important to guarantee at least the same resolution. A resolution of a few microns can therefore be considered sufficient for most applications. For applications were large deformations are expected this resolution largely exceeds the real needs A precision of 1% of the measured deformation is usually considered as sufficient..

4 Dynamic range

For applications in conventional civil structures, in-service deformations larger than 0.1- 1% of the gage length are rare. For geostructures, deformations of a few percents are on the contrary found in some applications. However, this means that for a 10 m long sensor, deformation of a few centimeters are expected. In this case a precision of a few microns is certainly overkill and other simpler methods (e.g. a rule) are certainly more appropriated than fiber optic sensors.

5 Stability

Since long-term applications are aimed, the resolution and precision cited above should remain valid even for measurements spaced by years.

6 Temperature sensitivity

All deformation sensors are also to some extent temperature sensors. It is therefore interesting to study the influence of temperature on the deformation measurements.

7. PRIORITY STRUCTURAL MONITORING RECOMMENDATIONS

Structural Monitoring (SM) is an indirect way of detecting the level of damage that has been done to a structure via natural or humaninduced disturbances. Structural Monitoring(1) was done using wired systems that collected and monitored data from these structures. This was an expensive and inflexible approach because the system could not be easily redeployed if better data collection points were discovered on the structure. Wireless Sensor Networks became a good way to solve this problem, and thereby meet a major requirement for a viable SM system. Autonomous motes could now be deployed over a field of interest while data was collected at a base station . The decision to use WSNs came with a significant tradeoff; bandwidth had to be sacrificed for flexibility and price. The radios on the sensors were not capable of transferring data at very high speeds, which also limited the number of motes that can be part of a single network. N. G. Shrive from the University of Calgary gives a description of the requirements for a SM system from a civil engineering standpoint(1). According to the work in that paper, an effective and deployable SHM system needs to have cheap, replaceable and durable sensors with some onsite artificial intelligence and lowpower requirements. This proposed system's onsite intelligence should be capable of determining failure in the sensors and power sources. The work(1) the use of wireless data transmission in order to avoid the risk of disruption to wires; wireless systems can also be easily replaced as advances in both software and hardware are made. Lastly, the system should be designed in a way that allows sensibility to certain structural response parameters that are calculated for the particular structure on which it will be deployed. Prior work done by Deepak et al. discusses the design of Wisden(1), a first generation wireless sensor network that is used for structural data acquisition. According to them, first generation network systems are likely to be used for data acquisition with much of the processing done at a base station node. Their main goal was to implement a reliable data transport as well as a wavelet based compression mechanism to deal with the issue of limited bandwidth. The work in this thesis focuses on implementing a second generation system with more data processing done in the network. Deepak's work implemented their system using the MICA mote, and its performance is compared to that of the IRIS (1) mote which was used to implement this project. D. Culler et al.(1) describe the implementation of a first generation SHM system on the south tower of the Golden Gate Bridge (GGB). This work identifies the requirements that a SM system imposes on a WSN and new solutions to meet these requirements are proposed and implemented. Although the current work in this area involves the traditional implementation of a SM system with a single data collection point, allusions have been made to a decentralized system as the future of research for bridge monitoring. With advances in semiconductor technology, it is becoming easier to manufacture motes with faster processors. This makes it possible to transfer the data processing tasks to the sensor nodes that make up these networks as shown in Fig.1.Wireless Sensor Networks have autonomous nodes that have a limited amount of energy supply, hence limiting the amount of processing and transmission that can be done on these sensors. The use of Wireless Sensor Networks for structural monitoring also introduces the issue of data security, making the implementation of a data encryption mechanism a primary goal.

System Architecture All these advancements in radio transmission rate and increased computational capacity in lowcost sensors make realtime structural health monitoring an interesting idea. Realtime data monitoring involves continuous data capture with a very small time margin between data sample blocks. The marginal time is represented as a percentage of total execution time, and the acceptable threshold will be set by the system designer. This idea forms the basis for this thesis work where a singlehop network will be observed and characterized for continuous data sampling and onchip computation.

8. EDITING STRUCTURAL MONITORING RECORDS

The concept of realtime means different things to different system designers, but for the scope of this project,it refers to a system that is capable of sampling data at a given frequency, with a very small time margin in between sample blocks. The major constraints of such a system for structural health monitoring are discussed below:

- energy: wireless sensors have a limited power source and this limits the amount of data computation and transmission that can be done. real time systems require continuous data sampling, processing and transmission, and this energy constraint poses a major restriction to the implementation of such a system,

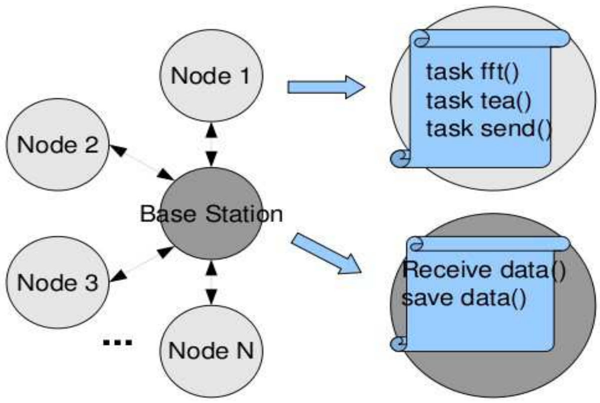

Fig. 1 – System Architecture(1)

- data transmission and storage: motes are very small computers that have limited memory on them. this limits the amount of data that can be stored intermediately prior to processing and transmission. intermediate data storage is a major part of realtime systems because information needs to be buffered in order to support the idea of continuous data sampling and transmission.
- sampling frequencies: the frequency at which data is sampled is critical to the successful implementation of a realtime system. the sampling frequency has to be high enough to detect the natural vibration frequency. however, sampling at a high frequency poses a few challenges. it results in more data points, hence requiring more intermediate data storage. it also means that more data will be transmitted over the radio hence utilizing more power. Although there are many factors that limit the implementation of a realtime system, it is still important to pursue scholastic ideas that explore the potential of the components that make up the system. this work can be categorized as a probe into the potential implementation of a realtime monitoring system.

According to Aktan et al.(5,6) health monitoring may be defined as "the measurement of operating and loading environment and the critical responses of a structure to track and evaluate the symptoms of operational incidents, anomalies, and/or deterioration or damage indicators that may affect operation, serviceability, or safety reliability". Structural management systems that have been realised by most infrastructure owners up to know do implement this concept by means of heuristic approaches, substantially based upon:

a) visual inspection techniques;
b) spot NDE techniques;
c) data processing and interpretation techniques;
d) information retrieval systems;
e) ranking systems based on qualitative condition indices.

In the recent years(5,6), both long-term and short-term instrumental monitoring are being proposed. Although these techniques are encountering increasing interest among infrastructure owners, extensive application is still lacking. When instrumental monitoring is used, comparison between forecasted and observed behaviour becomes a key issue in the determination of global condition indices and in the detection of the insurgence of local damaging. Advanced data processing and modelling techniques are therefore needed.

9. CONCLUSIONS

The structural monitoring is a legal process legislated in Romania the Normatve No.P130, which presents rules and technical aspects only from the static regime monitoring sphere. The development of structures as geometic,techic and volume features has lead to reveal the opportunity ,even the compulsory monitoring of structures in kynematic regime as well;the emergence in future of new methods,instruments ,manager-systems of the continuos monitoring,whatever of the response of construction features under the effect of different kinds of strength. (fig.3). The paper reveals the initiation of a MANUAL of STRUCTURAL MONITORING ,conducted through a partnership between the Technical Universitz of Cluj Napoca and University of Petrosani. Further research will develop the chapters of the manual ,final review and publishing is expected to be in 2014.

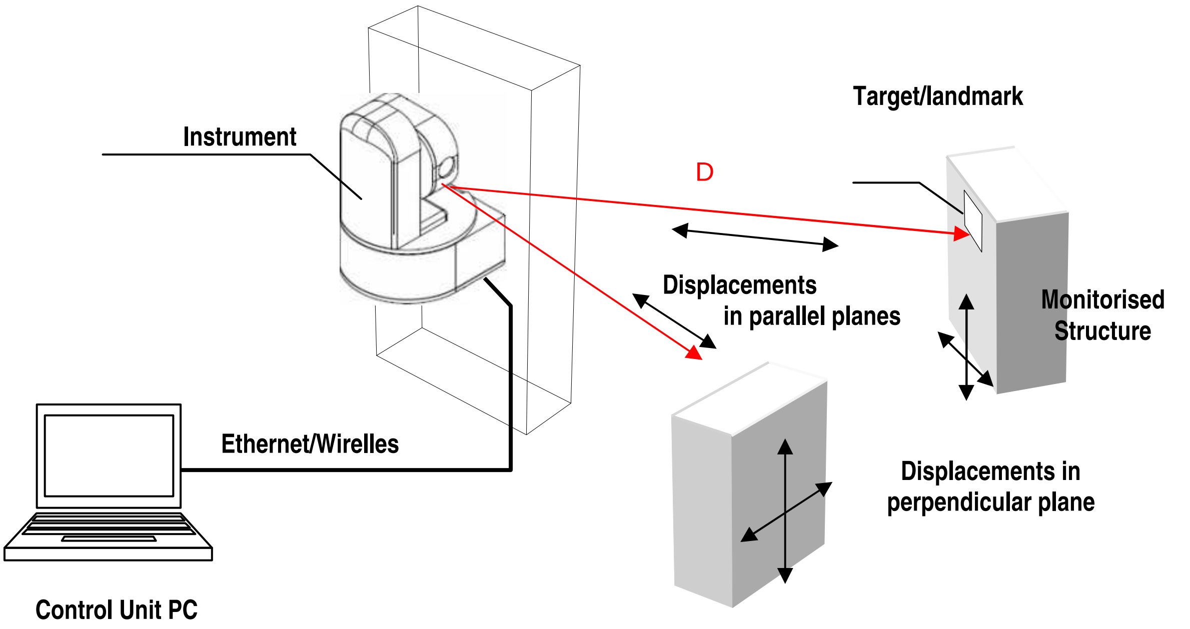

Fig.2 The principle of structural monitoring system in static and quasistatic

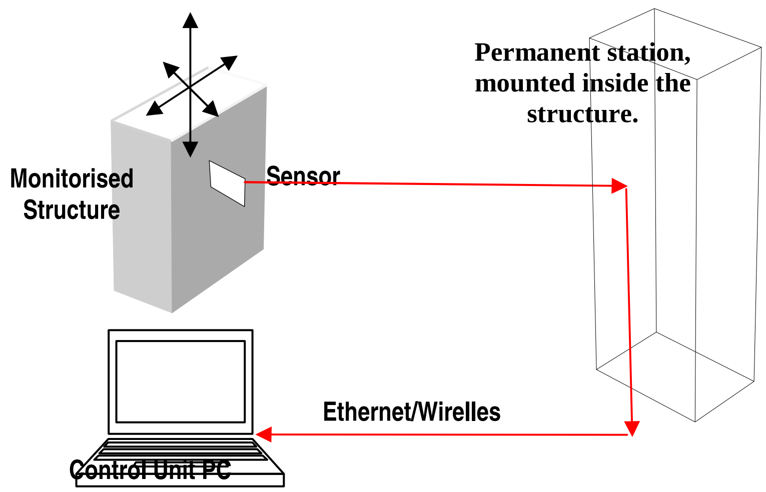

Fig.3 The principle of structural monitoring system in quasistatic and dynamic

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BIOGRAPHICAL NOTES

 **Adrian T. G. RADULESCU, Birth date July 17, 1982**

Teaching position Assistant Professor, North University Baia Mare, Romania
Undergraduate education The Faculty of Civil Engineering, Tehnical University of Cluj Napoca, 2006; The Faculty of Surveying and Cadastre, North University Baia Mare 2009, Master in environmental protection, 2008, management, 2010.
Scientific titles , PHD Doctor of Engineering Sciences, with the major of **Mining Engineering**, in the area of expertise of **Surveying, Thesis title:** "Modern surveying technologies used for tracking the time behavior of constructions within mining perimeters".
Scientific coordinator: Prof. Univ. Dr. Eng. Nicolae Dima, University of Petrosani, Romania
Scientific activity, Articles published in national and international field journals, in the books of some international scientific meetings – 42**,** Field manuals for higher education published by native or foreign publishing houses, Published Workbooks of problems and Tutorials – 6
Gheorghe M.T. Radulescu, professor in the academic area of Surveying, Engineering Surveying and Structural monitoring, North University Baia Mare, Romania
Virgil M.G. Radulescu, Assistant Professor, North University Baia Mare, Romania, PHD candidat Doctor of Engineering Sciences, with the major of Mining Engineering, in the area of expertise of Surveying**,**
Vassilis Gikas Assistant Professor in Geodesy, School of Rural and Surveying Engineering, National Technical University of Athens, Greece. Vassilis Gikas received the Diploma degree in Surveying Engineering from the National Technical University of Athens, Greece and the Ph.D. degree in Kalman filtering and Geodesy from the University of Newcastle upon Tyne, UK, in 1992 and 1996, respectively. He is currently an Assistant Professor with the School of Rural and Surveying Engineering at the National Technical University of Athens, Greece. His principal areas of research include sensor fusion and Kalman filtering for mobile mapping applications, engineering surveying and structural deformation monitoring and analysis.

CONTACTS

Adrian T. G. RADULESCU
Technical University of Cluj Napoca
North University of Baia Mare Center
Str.dr.Victor Babes, nr.62A
430083 Baia Mare, Romania
Tel. +40721942189
Fax + 40262276153
Email: gmtradulescu@yahoo.com
Web site: www.utcluj.ro, www.ubm.ro