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DYNAMIC CHARACTERIZATION OF BUILDINGS USING WIRELESS SENSOR NETWORKS

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ABSTRACT:
Dynamic characterization of structures is a tool that can help to determine its actual state. Also, allows calibrating finite element models. Traditional methods use a centralized data acquisition system. This approach is not scalable since the cost of each channel may forbid it. A new paradigm to instrument structures uses smart sensors, capable of wireless data transmission, and local processing. With this technology is possible to eliminate the use of cables and reduce installation time. First the best location for the sensors is established based on modal participation of the sensor placements. The second task is to design a network capable to transmit the data in the most fashionable way. The objective of this paper is to present two different networks that together permit transmitting data collected over the structure without buffer overflow.

KEYWORDS: Wireless network, smart sensors, ad-hoc network.

1. INTRODUCTION

Instrumented structures are a rare characteristic all over the world. Without this peculiarity is not possible to determine its dynamic behavior before, during and after a seismic event. Some of the benefits of structural instrumentation are: a) determination of the dynamic properties, b) knowledge of the behavior in service conditions, c) monitoring of the structural performance at induced excitations, d) detection of potential danger due to the damage in the structure and, e) security revision of the structures design with previous regulation. Furthermore, the information collected from the monitoring of the structures can be use for hypothesis verification and results of diverse mathematic models, in particular those concerning with fine element models. Other benefits are the extrapolation of the actual response of the structure with respect of that expected during a strong earthquake. Finally, to facilitate the take of decisions over structures that can be rehabilitated. All with the objective of safeguard its occupants.

The reasons because instrumentation is not common practice are a) the high installation and maintenance cost, b) the lack of methodologies for adequate instrumentation and, c) the lack of knowledge for the application of the new technologies

New technology is available to reduce cost of instrumentation. By reducing installation cost, as well as maintenance, wireless sensors promise to be the nest paradigm. To achieve the implementation of network of wireless sensors it is necessary to overcome issues related to the information management, communication between sensors, placement location and number of sensors, among others.

The objective of this paper is to present some of the methodologies for best sensor placement, and the design of an adequate network capable of send the data without overflowing the memory buffer of the sensors.

This paper has the following structure; in the first section a brief overview of the methodologies for optimal sensor placement is presented, the following section a definition of distributed algorithms. An analytical implementation on a plane frame is presented and finally a proposal for a network formation is developed.

2. OPTIMAL SENSOR PLACEMENT

The optimal sensor placement of sensor has been a research topic in the last years. Shah and Udwadia (1978) were one of the first in authors in this topic. Their paper investigates the best sensor placement for estimation of dynamic properties; the solution is based on the covariance matrix. Later Udwadia (1994) propose a methodology based on the Fisher information matrix that is applicable for linear and nonlinear systems.

Heredia (1996) presents guidelines for optimal instrumentation based on the loss of the Bayesian information. Heredia at al. (1999) extended their previous work to be applied to structures constructed over soft soil. The goal was to investigate the effects of this type of soil on the instrumentation system.

Ka-Veng et al. (2001) presents a methodology to propose optimal and rental systems of sensors for model update, and structural health monitoring. This selection is based in the entropy of the uncertainty information. The methodology determines the number of required sensors and their location based on the desired modal shapes.

Finally, Cherng (2003) presents a methodology based on the analytical formulation of singular value decomposition for a candidate-blocker Hankel matrix using Signal Subspace Correlation (SSC). The advantage of using SSC is that takes in account the mode shapes, damping ratios, sampling rate and matrix size. The author proposes two methods that are based on modified versions of the Lim-Gawronski (1995) method and Bayard-Hadaegh-Meldrum (1998). The methodology proposed by Cherng was used in this paper.

2.1. Wireless networks

Now days the presence of wireless communications has been increased in a considerable way. There are different technologies that we used day by day depending with the needs to be satisfied. As example the cell phone has become an indispensable accessory. Technology modifies the way that we live, works and interact. In the subsequent years is to be expected for us to be capable to monitor physic, chemical and biologic phenomenon, among others with a sophisticated level without limits and with biologic methodologies with accessible cost. Sensor in a sort time will be implemented in the big cities, main road, machinery, farm fields, forest and deserts, furthermore in places where is difficult or impossible for a human being to be (ocean depths, chemical and ambient disasters or even other planets).

A sensor is design to act as high level information processor in task related with detection, searching and classification. Each one of the task need to be develop in the sensors are well defined, including detection of: false alarms, classification errors and tracking.

Sensors are sources of information so diverse as well as the measures done by them. There are sensors that record temperature, light intensity, pressure, humidity, velocity, acceleration, presence, volume and some other magnitudes. If in addition to theses measurements with add the capability of wireless communication and the possibility of ad-hoc networking, we will get as result efficient systems that can help to solve actual problems.

M. Frodigh, P. Johansson and P. Larsson (2000), presented numerous factors associated with the technology, Business, regulations and social behavior. These factors suggest in a natural and logic way the formation of ad-hoc wireless networks.

In general an ad-hoc network consist of nodes that use and wireless interface to send data packages without any central administration. Due to the fact that the network nodes can serve as routers can send packages in name of other nodes and execute the user applications.

Nevertheless the technologic advances in the new generations of sensors raise other challenges. These are related with the information process trough the network, scalability problems and the overflow of channels. In addition, failure in the local nodes, battery collapses or physical damages of the sensor. With the objective of deal with these problems is necessary to implement an ad-hoc network fault tolerant.

3. DISTRUBUTED ALGORITHMS

R. Marcelín [9] define a distributed system as the heterogenic sum of components of hardware, software and data, interconnected by some type of communication network to collaborate in offering a service related to information management. Also, mentions that the difficulties in the construction of these systems are related to the limitations of the components. It is desirable for the system to guarantee the quality of the service, even of a number of the components fails or deviate from the operation specification. The distribute systems can be divided in two main categories:

a) Messaging passing
b) Share memory

The first one emphasizes the role of the communication network. It is described as a non-directed graph G=(V,E) (figure 1), in which the group of nodes V, represents the network processors; and the group of the joints E, represents the bidirectional communication channels that interconnect the machines and where messages are exchange.

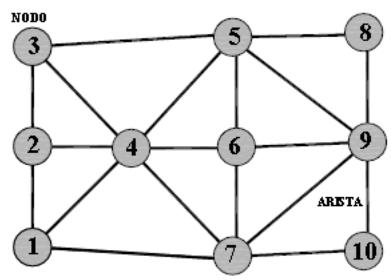

Figure 1 Graph G=(V,E)

In the second category the process communicates carrying out operations of storage and recover of the information over a common organized space of share objects. These objects could be read/write registers, tails or registers with atomic operations of the type test&set

Distributed algorithms can be defined as a recollection of autonomous process that share information for the realization of a common task. Each process that runs its local version of the distributed algorithm can be characterized as a joint of finite process, a finite group of communication events, and a finite group of atomic transactions between states, trigger trough communications events.

For the construction of a tree generator exists various methods. Among them are two of the most used approaches: Depth First Search (DFS) and Breadth First Search (BFS).

Even though both methodologies build a tree, there are differences in complexity of the algorithm, as well as in the properties of the erected trees. Such characteristics can be used in benefit of the solution of the problem.

It is fundamental to understand the construction and behavior of a generator using the methodologies before mention, since they are the key in the solution of the problematic concern to the connectivity of a wireless network, as well as to the information management.

3.1. Construction of a Depth First Search (DFS) tree.

T. Cheung (1983) and I. Cidon (1988). At the beginning of the algorithm the participant process have the same code instructions, for that reason is said that exist an initial symmetry in the group. Is frequent in the distributed programming to give privilege to one of the process of the system and with that the initial equilibrium is broken.

The DFS algorithm begins when this fracture of the symmetry. It can be said that *s* initiate the flow of the turn, or activation message, in which other process is selected to have the execution control. Only the process that possess the turn is consider active, for that reason there is only one algorithm execution in this conditions.

In every place a process mark the link from the who receive the activation message for the first time and select a new road from which has to give a new turn to initiate the algorithm in other part of the system, them the local execution is stopped and waits news from this neighbor that has receive the return, that is, the process with the neighbor that share the link through which the turn travels.

When a process cannot retransmit the turn, because does not have neighbors or because has visit all that it can, then sends a new message through the marked link to return the control of the process to its predecessor, call father, in that precise moment all local executing process is finished. In the other side of the link, the receptor design son to the neighbor that has return the action. Every time that this happens the process tries to resend the turn to activate other neighbor; if it does not get it stop its execution until receive answer, if not returns the control to its own father and stops.
There are times in which one process receives a repeated message of activation for a different link than the original, form a neighbor that ignores its local condition; in such case the receptor should answer with another message in which inform the state of its execution and the impossibility to be assign son since there was another one that activate it previously.

Some time the execution turn return to *s*, and if there are no more road to travel, then the execution if terminated completely. When this happened, every process is in the possibility to distinguish the links that communicates it with its father and son.

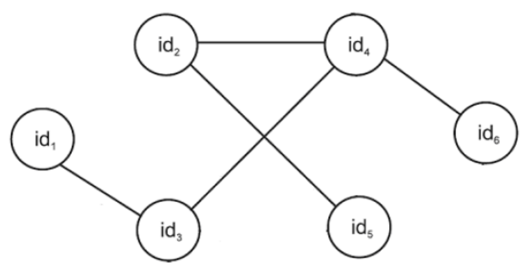

Figure 2 Tree constructed by and DFS algorithm (Marcelin 204)

3.2. Construction of a tree using Simple Propagation (SP)

A. Segall (1983). Consider a G graph in which exists a process s that has to be transmitted a message to all other places of the system. To achieve this it is requires at least for G to be convex, that is, exists a road between any of the couple vertex.

The diffusion or propagation problem, as know it, appears repeatedly in the process of distributed systems. Example of its applications is: to calculate the shortest route between two arbitrary places, to develop connectivity test, to recognize changes in the network topology.

A first approach for the solution of the propagation algorithm can be obtain modifying the Depth or Breath Search (DS and BS) algorithm to adapt it to the requirements of propagation. This is the protocol logic of the SP that uses the BS. Over a network in which is suppose there are no global clock *s* sends a message to each one their neighbors, They receive it and resend it for each one of their communication lines. All the process that receives this information as well does exactly the same operations.

The process finalized the execution as soon as send the message to its neighbors. It is easy to verify that the execution of the algorithm ends satisfactorily and that any process receives the message provided by *s* (figure 3).

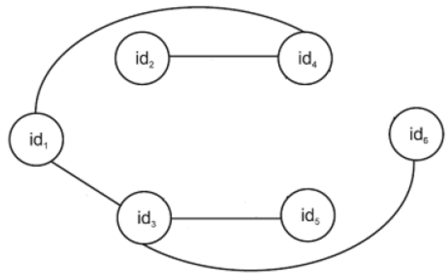

Figure 3. Tree constructed by and BFS algorithm (Marcelin 204)

4. SENSOR PLACEMENT

After presenting different approaches for best sensor placement, this paper will use the methodology proposed by Cherng. This integrates two important aspects for optimal sensor placement: the geometric weight of the sensor (its location within the structure), and the obtained data. Furthermore, in this methodology converges some of the criterion studied by other authors. For space reasons only a brief summary of the most important aspects of the methodology is presented.

4.1. Lim-Gawronski (LG) approach

Based in the Hankel Singular Values (HSV), the LG method ranks a sensor for its contribution of with respect of the targeted modes. In this sense, each sensor can be evaluated with respect of the total contribution of the set of sensor placement. The total contribution of a sensor placement set is define as the trace of the H^TH (where H is the Hankel matrix)

$$\gamma^2 = \text{trace}\left(H^TH\right) \tag{4.1}$$

$$\gamma_i^2 = \sum_{r=1}^{n} \tilde{\gamma}_{ir}^2 \tag{4.2}$$

In the equation (4. 2) $\tilde{\gamma}_{ir}^2$ represents the contribution of the ith sensor to the rth mode, and γ_i^2 represents the contribution of the ith sensor over the n targeted modes.

4.2. Bayard-Hadaegh-Meldrum (BHM) approach

The BHM approach has two steps, first adds each modal contribution over all sensor locations, and later ranks the product of the contributions. The square root of the modal determinate of H^TH is simply the product of all modal HSV of H.

$$S = \det(H^T H)^{1/2} \infty \Psi \tag{4.3}$$

$$\Psi = \det(diag(\Phi^T \Phi)) \tag{4.4}$$

Equations (4.3) and (4.4) indicate that the product of the HSVs and S, are proportional to the placement index Ψ, which is also the Fisher Information Matrix of the BHM.

4.3. Difference between LG y BHM approaches

LG approach selects the sensor placement location based on the information collected at sensor with respect to the n targeted modes. That is, only takes in account the arithmetic mean without weighing the location of the sensor.

The BHM methodology pick the sensor placement location based on the information of the mode shapes at the m sensor location. That is, only takes in account geometric mean without weighting the information of the sensor.

To take advantage of these two methodologies Cherng proposed a strategy for sensor placement using SSC. With this approach the LG and BHM methods can be unified. The first step is to normalize the modes before ranking them.

$$\rho_{ir} = \frac{\varphi_{ir}^2}{\sum_{i=1}^{m} \varphi_{ir}^2} = \bar{\rho}_{ir} \qquad 0 \le \varphi_{ir}, \quad \bar{\varphi}_{ir} \le 1 \tag{4.5}$$

Where

$$\sum_{i=1}^{m} \rho_{ir} = 1 \qquad \forall_r \tag{4.6}$$

Expressing the previous equations in a matrix form

$$\Gamma = \begin{bmatrix} \rho_{11} & \rho_{12} & \cdots & \rho_{1n} \\ \rho_{21} & \rho_{22} & \cdots & \rho_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \rho_{m1} & \rho_{m1} & \cdots & \rho_{mn} \end{bmatrix} = [\rho_1 \quad \rho_2 \quad \rho_3 \quad \rho_4] \tag{4.7}$$

So, the contribution of the ith sensor over all targeted modes is:

$$\rho_i = \sum_{i=1}^{n} \rho_{ir} \qquad 0 \le \rho_i \le n \tag{4.8}$$

$$\sum_{i=1}^{m} \rho_i = n \tag{4.9}$$

The ranking of the sensor is based on the ρ_i numerical value.

5. ANALYTICAL APLICATION

A planar frame was used for the implementation of this methodology with 90 sensor locations (see figure 3).

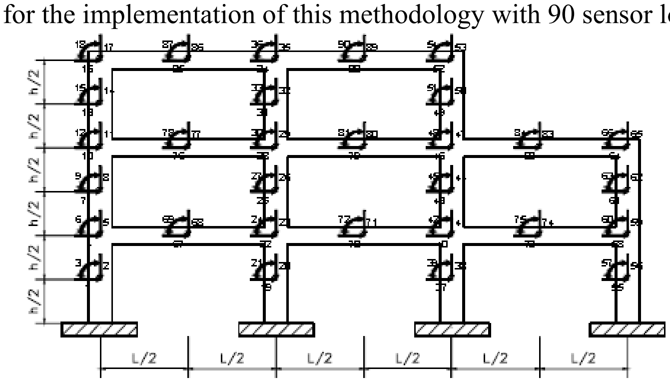

Figure 3: Planar frame with 90 sensor placement locations.

5.1. Sensor connectivity

After selecting the sensor locations five connectivity arrangements were investigated, these are shown in figure 4. The location of the central node, in which all the information will be concentrated, was also investigated. Five possible positions were selected at nodes: 1, 21, 27, 30 and 33 (see figure 5), named A, B, C, D and E respectively.

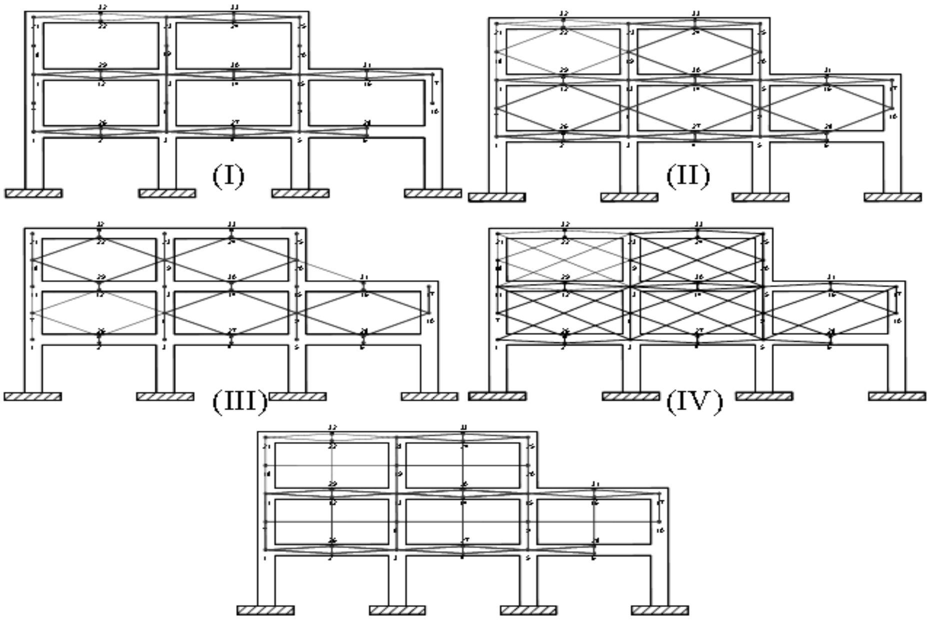

Figure 4. Proposed connectivity trees.

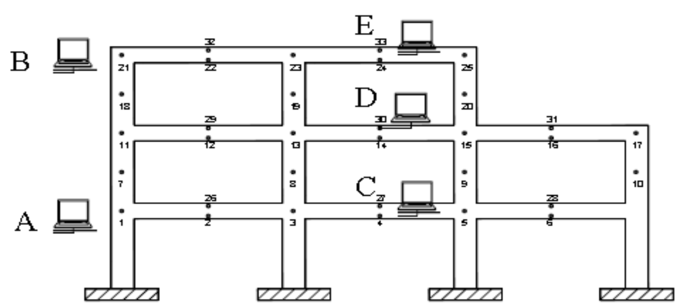

Figure 5. Locations of the central node: A, B, C, D and E

The DFS is first implemented, this will construct connectivity tree with only one threat. This tree constitutes a layer that will be used to assure that no collisions are presented in the network. Later a BFS is conducted over the network. This layer will be used as route for data retrieval, and will assure the robustness of the network. A computer program was developed to simulate the data transmission in the network. The variables involved were: sweeping period, buffer size, channel bandwidth, bits generated by the sensor.

The sweeping period is the time imposed to the net in which the central node commands to the nodes to send their storage data. Buffer size, channel bandwidth and the bit generated by the sensor were fixed according with the specifications of the Berkeley Mote platform [10]. For space reasons figure 5 only shows the results for the frames III and VI with all five central node locations. The sweeping period was set in 400 seconds.

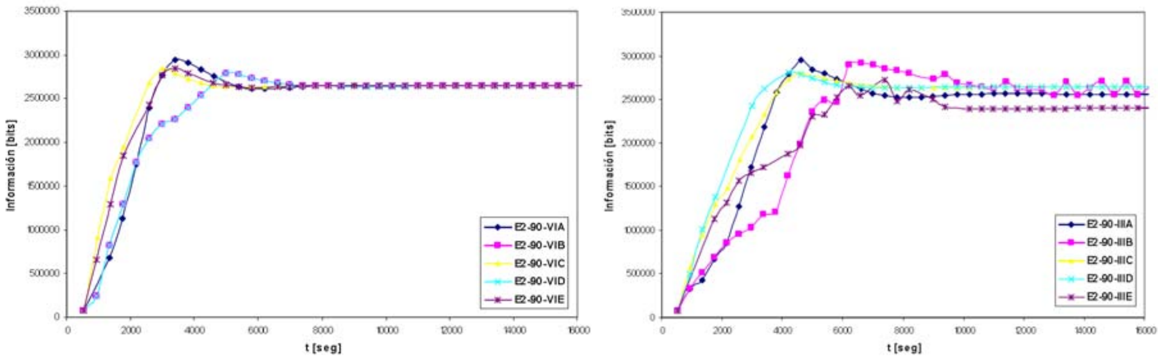

Figure 6: Information bits vs. time. Frames III and IV.

6. CONCLUSIONS

A methodology for sensor location that combines arithmetic and geometrical mean was implemented in a plane frame. Five interconnection routes and central node locations were studied. A network connectivity methodology that combines the DFS and BFS approaches was developed. Simulations shown that the time required in reaching maximum data collection depends more in the interconnection route than the central node position.

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