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STUDY ON STRUCTURAL HEALTH TESTING AND MONITORING OF BUILDING

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ABSTRACT

The rapid development of inexpensive smart wire sensing devices has triggered the onset of a revolutionary transformation in data acquisition and reconnaissance paradigms, the likes of which can be harnessed for vibration-based structural health monitoring (SHM). Referred to as simply a "mote", these devices integrate a micro-processor, computational memory, and a radio transmitter into one small battery operated instrument and are often equipped with a low power MEMS technology sensor. Since the mote-sensor combination has the ability to virtually listen, think, and talk the development of a smart wire sensor network for infrastructure preservation is an advantageous prospect for the vibration-based structural health monitoring community. Deploying large ensembles of motes could allow for automated feature extraction, damage identification, and coordinated response decisions to be made online through embedded adjudicatory algorithms. However, despite the promising attributes of a wire sensor network there are limitations which need to be addressed. Recent studies have shown that streaming data over the low power radio communication links at rates sufficient for SHM results in data losses and is too power consumptive. As such, there is a need to decentralize the traditional infrastructure monitoring system concept in order to better exploit the onboard computational facilities of a mote. Hence the motivation of this work is to develop and test the efficiency of a vibration-based condition assessment algorithm which can be embedded within a wire smart wire sensor for structural health monitoring.

Keywords: *Monitoring, damage detection, localization, assessment, consequence, solution*

I.INTRODUCTION

Infrastructural health monitoring or condition monitoring by way of a structure's global dynamic behavior is not a new concept. It has been suggested that some of the first clay potters would strike their fired clayware and listen to its tone as a way to determine if the vessel was flawed. The artisan understood that any deviation from the expected norm in the tone indicated the presence of a defect in the work. This is quite an impressive discovery and an interesting point to make since the oldest known collection of pottery has been dated to as early as 10,500 BC.The same concept applies to other structures, and this effect is the central motivation of global vibration-based structural health monitoring. There are really only two fundamental differences between the monitoring done by ancient potters and such systems today. The mathematics behind the monitoring process are better under-stood, i.e. for some linear systems close-form expressions for oscillatory motion can be developed, and instead of the human ear innovative sensing devices are used to record data. Despite these changes virtually the same monitoring process is performed today. Presently in the India structural integrity is monitored by simple techniques such as visual inspection, concrete sounding (hammer echo), dye penetrated, and ultrasonic. These condition monitoring techniques can provide strong indications of the presence of damage if tests are performed on potential damaged areas. This means that if there is no prior knowledge of damage the structure must be scrupulously examined and that the inspector is well trained in diagnosing test results which may only reveal potential symptoms of damage.

II.EXPERIMENTAL INVESTIGATIONS

MICRO ELECTRO MECHANICAL SYSTEM:

Micro-electro mechanical systems (MEMS) were developed through what is called the very large system integration (VLSI). VLSI is the process of placing thou-sands of electronic components onto a single silicon substrate using micro–fabrication technology. MEMS integrate mechanical elements with the electronics required to operate them on a single chip. As such, complete systems-on-a-chip can be developed. MEMS technology has already shown it has much to offer the health monitoring com-munity by developing complete ultra small, low power sensor and actuator hardware.

MEMS ACCELEROMETER

III.METHODOLOGY

Under existing vibration-based SHM paradigms, which are developed around centralized data processing, it is unlikely that a remote wire sensor will

prove to be an advantageous alternative. If vibration-based structural health monitoring paradigms are shifted to exploit the onboard, low power processing facilities of smart wire sensors, then several key improvements could be made. Namely, a smart wire sensor network used for vibration-based health monitoring may be able to:

- **Curtail sensor deployment costs**
- **Curtail data acquisition hardware costs**
- **Increase sensor coverage**
- **Increase monitoring fidelity**
- **Increase monitoring adaptability**

It is now the work of the engineer to a design health monitoring systems which can function within the limitations of these new devices. As such, this work focuses on developing a distributed-process, vibration-based health monitoring paradigm for implementation on a smart wire sensor platform. Then to validate the algorithm examined in this study, two proof-of-concept experiments are discussed using unmodified commercially produced motes equipped with MEMS accelerometers Finally, this work concludes with a numerical sensitivity analysis of the proposed feature correlation metric implemented within the developed SHM algorithm .

Global Linear System Dynamics:

The theoretical basis behind global vibration-based structural health monitoring is presented. The modal parameters of a structure can be obtained via experimental response time history records are introduced.

i)Theoretical ParameteFormulation:

Consider a structural system with mass, damping, and stiffness which has been excited by an impulse and is presently undergoing free oscillatory motion. If the materials strain in a linear elastic manner and dissipate energy at a rate, proportional to velocity then the behavior of the system will adhere to the laws of simple harmonic motion. As such, a close form expression can be derived.

ii)Multiple Degrees of Freedom System Dynamics :

Now consider the generalized multiple-degree-of-freedom system. Again using Newtonian mechanics the same second order homogeneous differential Equation of motion as that of a single degree-of-freedom system can be written only now in a matrix form, cf. .

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{0\}$$

Consists of n linearly dependents of motion. If a similarity transform is used the expressions can be decoupled into n linearly independent equations. As such, the single degree-of-freedom solution procedure is valid for each of the decoupled.

Interestingly, another modal parameter can be obtained from the multiple degree-of-freedom system s. In addition to the natural frequencies (ω_n) and damping ratios (ζ), mode shapes (φ) can be obtained. Mode shapes describe spatial characteristics of each mode of vibration and are often a useful parameter worth observing for 17 vibration-based SHM. Here again the system modal parameters are fully dependent on the system's mass, damping, and stiffness characteristics.

iii)Experimental ParameterFormulation

When a global vibration-based monitoring scheme is implemented often the actual system characteristics are not known a priori and must be measured. This is usually done by instrumenting a structure with sensors which measure and record the dynamic response, x(t), derived in the previous section. As such, these response time histories can then be analyzed a number of different ways to extract the system's modal parameters. In this thesis a frequency domain analysis technique known generally as power spectrum analysis is implemented since it lends itself well to a distributed autonomous health monitoring scheme. The first spectral estimate of a data time series is credited to Sir Aurther Schuster in 1898. In his work titled, "On the Hidden Periodicities of a Supposed 28 Day Cycle" he characterized the emergence of sunspots by developing a new mathematical tool for tracking the frequency of the occurrences. He called this tool the periodogram. Since then his work has been realized by others as a way to characterize all types of cyclical behavior. The process by which frequency analysis is presently conducted today is now recapitulated.

IV.SPECTRAL ANALYSIS

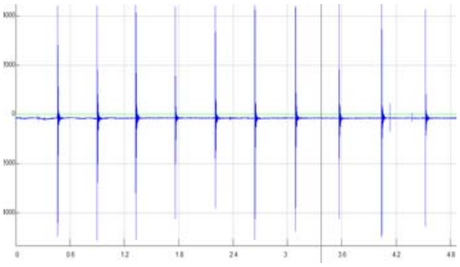
Typically the responses of a system are acquired with accelerometers. As such, acceleration response time histories, i.e. $\ddot{x}(t)$ not x(t), are analyzed to extract modal parameters which are then used in a vibration-based SHM technique to make assessments concerning the safety of a structure. The reader should note that this is acceptable since the harmonic acceleration response at a given frequency, $\ddot{x}(t)$, only differs from the displacement, x(t), by a scaling parameter. As such, useful modal information may still be extracted from this data.

Here the pictorial representation of spectral analysis over several buildings are been given below

ANALYSIS OVER FIRST BUILDING

This building is situated in Mogappair. It was learned to be constructed in the year 1995. We made our typical analysis over this building

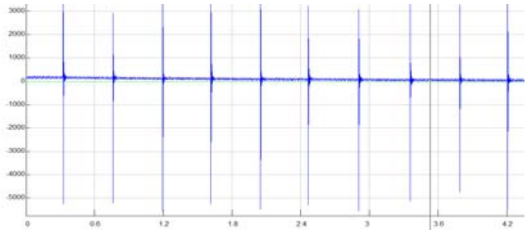
This is the graphical representation of the frequency wave of roof of the above mentioned building, which is recorded in the Sigview software



ANALYSIS OVER SECOND BUILDING

This building is situated in Mogappair West. This building was learned to be constructed in the year 2007. We made our typical analysis over this building.

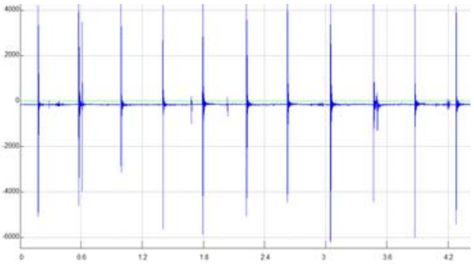
This is the graphical representation of the frequency wave of roof of the above mentioned building, which is recorded in the Sigview software



ANALYSIS OVER THIRD BUILDING

This building is situated in Mogappair west. This building was learned to be constructed in the year 2000. We made our typical analysis over this building.

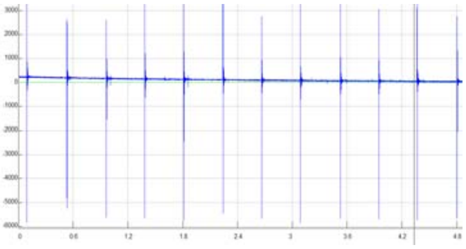
This is the graphical representation of the frequency wave of roof of the above mentioned building, which is recorded in the Sigview software.



ANALYSIS OVER FOURTH BUILDING

This building is situated in Vadapalani. This building was learned to be constructed in the year 2010. We made our typical analysis over this building.

This is the graphical representation of the frequency wave of roof of the above mentioned building, which is recorded in the Sigview software.

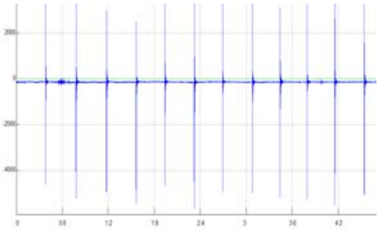


ANALYSIS OVER FIFTH BUILDING

This building is situated in Vadapalani. This building was learned to be constructed in the year 2003. We made our typical analysis over this building.

This is the graphical representation of the frequency wave of roof of the above

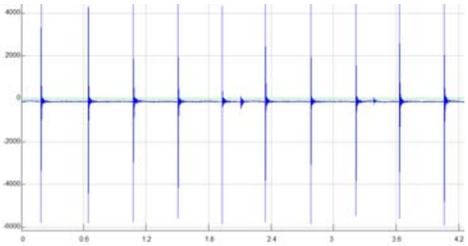
mentioned building, which is recorded in the Sigview software.



ANALYSIS OVER SIXTH BUILDING

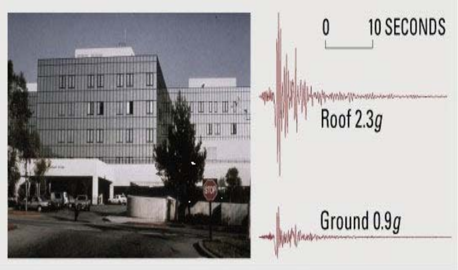
This building is situated in Mogappair West. This building was learned to be constructed in the year 1993. We made our typical analysis over this building.

This is the graphical representation of the frequency wave of roof of the above mentioned building, which is recorded in the Sigview software.



Complex-curve Fitting

Often mathematical methods are used to automatically extract natural frequencies from power spectrms. In 1959 E.C. Levy presented a novel complex-curve fitting technique to extract features from system transfer functions. Based on the minimization of the weighted sum of the squares of the errors between the magnitude of the actual function and a polynomial, H(iω), this numerical method can also be used to automatically pick the peaks of a power spectrum.



SOFTWARE ANALYSIS

Distributed SHM Algorithm for SWSN

In this chapter a structural health monitoring strategy is developed in collaboration with for needs of a distributed process data acquisition system. The literature indicates that the potential of vibration-based SHM coupled with smart wire sensors has not yet been fully appreciated. Consider which illustrates the transmission paths of both a smart wire sensor network and a group of smart wire sensors. To date, SWSs and SWSNs have been cond in civil

engineering applications to operate in a fashion consistent to that of a centralized data acquisition system. While complex routing and compression algorithms have been embedded on motes to increase transmission reliability, the end objective has been to send all data to one centralized collection center for post-processing.

Despite new advancements in wire radio transmitters, better radios themselves do not appear to be able to address the demands of a dense wire sensor network as envisioned for health monitoring. That is to say that transmission power consumption, radio bandwidth, and latency attributed to data compression schemes will continue to stand in the way of the development and implementation of a full-scale SWSN for centralized SHM. Clearly, the idea of using a dense SWSN that can exchange reduced sets of data to increase the global sensitivity of an SHM method would be advantageous. As such, distributed SHM algorithms which extract meaningful features from response data without multiple channels of data need to be embedded on SWS.

Feature Correlation-based SHM

Feature correlation-based monitoring techniques essentially function by comparing the characteristics a numerical model to those of the actual structure. In general, these methods are implemented according to the following concept. Mathematical features are extracted from measured structural response behavior and compared to a database of features extracted from response behavior generated by a numerical model of the structure. The numerical model is damaged in various ways to simulate all, or nearly all, of the likely damage scenarios. A strong correlation between a set of observed structural features and those features generated by way of a numerical model can indicate the actual structure’s condition is I.e. one can assert the actual structure is damaged in the same way the model is damaged.For example, here the real structure is a vertical cantilever beam. Notice the “healthy” finite element model depicted. The healthy numerical model is used to generate and subsequently simulate all of the possible damage scenarios. (Several of which have been illustrated alongside the healthy model.) The damage models are then used to generate mathematical

features which are correlated to those extracted from the real structure. If a strong correlation exists between a particular damage model and the real structure, damage is identified and located on the actual structure according to the damage case simulated in that model. The drawback to a correlation-based technique is that nearly all of the possible dam-age cases need to be generated in order to reliably detect and localize damage. If multiple damage scenarios are considered the database of damage cases can become immense and database generation becomes computationally intensive. To circumvent this problem in the past researchers have used genetic algorithms or statistical-based recognition methods [28, 39]. These methods are seen as more or less the precursors to more advanced correlation-based techniques which entail artificial or probabilistic neural networks (P/ANN).

These networks are the most recent of the monitoring techniques to be developed and they function by training themselves to associate damaged features to certain sets of prescribed outcomes. Considering all of the uncertainties associated with vibration based health monitoring this P/ANN.

Damage Location Assurance Criterion

In this study the Damage Location Assurance Criterion (DLAC) correlation method developed by Messina et al. (1996) is utilized. The proposed method was developed from the Modal Assurance Criterion (MAC). A MAC value measures the extent of linear correlation between an experimental and analytical mode shape and is typically used for validating the fidelity of an analytical model, and as such the metric is very similar the inner product vector operation. In their work Messina et al. show that the MAC concept can be extended damage localization by comparing natural frequency characteristics of a model with the actual structure. A general framework of the distributed health monitoring technique implemented in this study is now outlined,

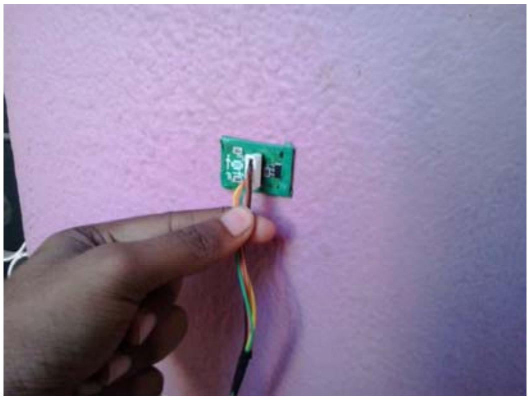
Step I: SWSs are deployed onto the structure and a finite element model is developed. The mesh and sensor locations do not need to correspond exactly.

Step II: SWSs are initialized to gather "healthy" structural response data and to extract "healthy" observed features, $\{O_j\}$. The finite element model is used to simulate damage

scenarios and to generate hypothetical damage features, $\{H_j\}$.

Step III: Hypothetical damage feature databases are wirely mapped (uploaded) to each deployed SWS. SWSs receive a particular damage identification database according to its spatial orientation on the structure.

The motivation for developing a distributed SHM algorithm has been explained. The concept of health monitoring with a smart wire sensor network versus that of monitoring with smart wire sensors has been graphically illustrated. The principle behind feature correlation-based SHM paradigms has been introduced. Based on current power and data reliability limitations of commercially manufactured SWS, a natural frequency-based correlation technique known as the Damage Location Assurance Criterion (DLAC) was introduced for the studies conducted in this work.The DLAC metric and localization methodology can be implemented without multiple channels of synchronized data. Thus is viable monitoring alternative for distributed structural health monitoring. Finally, the framework for using the proposed damage localization technique when implemented in a real structure was also presented. As such, in the forthcoming chapter the methodology will be validated experimental.



Damage Localization

A simple 5 degree-of-freedom lumped parameter numerical beam model was used as the identification model in this study. Each damage scenario was simulated with a 10 percent reduction in inter-storey column stiffness. The results of the DLAC correlation are presented.

In this chapter damage identification and localization has been successfully performed with both the Mica2 and MicaZ mote sensors. The MTS310 multi-sensor board proved to capture accurate response behavior below 25 Hz and despite data losses attributed to wire transmissions the natural frequencies obtained corresponded well with those identified using wired accelerometers and more sophisticated signal processing software.

Simulation Procedure

To facilitate the intensive computational analysis presented in this chapter a three stage analysis program was created in MATLAB. The scheme of this program is outlined and can be summarized into the following three levels.

Level I: Here Euler-Bernoulli finite element beam models of various refinements are assembled and suites of natural frequencies are generated. There is one suite of frequencies per model generated. Suites consists of a set of natural frequencies. For each simulated damage location. In this study natural frequencies are per-turbed to simulate damage and frequency perturbation is achieved by adding a lumped mass to individual nodes.

Level II :Here a user defined text file is accessed by the program. This input file consists of a list of FE models (created in Level I) which will be loaded into the DLAC simulation program for comparison. Within the input file the user also defines one particular FE model to be the simulated "actual" structure, all other FE models called in the input file are then used as identification models in the DLAC identification algorithm. Once the DLAC simulation program com-mences the user can select the number of modal frequencies for the correlation procedure and the percentage of measurement noise to impart on the system. All performance metrics are calculated here and then printed in an output file.

Mot
e

Level III :Here several post-processing routines were created to generate the various success rate summary statistics from the information printed in the Level II output files. In this chapter the parameters which are investigated to

determined their affect the on the accuracy and overall efficacy of the DLAC method are spatial quantization, hypothesis damage intensity, and modal truncation with respect to noise.

GENERALIZED PARAMETER

i)Sensitivity to Spatial Quantization

The average L_d value for various model ratios, M, and damage intensities, D, are presented. Notice the effect of spatial quantization has on the accuracy of the DLAC localization method. Values which are within the limits of the success criterion are denoted by italics. When M = 0.063, the model is much too coarse to attain localization values within the success criterion limit imposed for all values of D. Notice that when M = 0.125, despite distances between each node being greater than the success rate criterion, 6.75 inches on center, the DLAC procedure can capture results within the threshold for nearly all values of D. Of course, the as the model ratio approaches unity, the average L_d value continues to decrease. These uncorrupted results, i.e. no noise addition, indicate that spatial quantization should be considered when implementing the DLAC method.

ii) Measurement Noise

To simulate “actual” natural frequencies, the identification model’s frequencies are seeded with noise according to 5.1. Since the distribution of errors pro-duced by a fractional polynomial curve-fitting technique are unknown the effects of both uniform and Gaussian distributions of noise are implemented. The range of the uniform distribution is -1 to +1. The Gaussian distribution has a zero mean and standard deviation of one. Success rates were determined from 50 trials. To consistently compare results from all tests 50 sets of 30 random numbers (for each distribution) were generated in MATLAB and stored. As such, the same random numbers were used for each different test conducted. Historgrams of the 50 sets of each type of noise used in the study are presented .

iii) Modal Truncation

Consider the uncorrupted results presented in Table 5.2 in which five natural frequencies were used in the correlation procedure. Again, values which are within the limits of the success criterion are listed .Note, here again all values of damage ratio, D, performed in similar fashion. Only Gaussian noise needs to be implemented to establish a conservative estimate of the reliability of the DLAC localization procedure. Notice as the number of natural frequencies used in the correlation is increased from 1 to 15, the success rate increases from approximately 0.5 percent to 60 percent with an imposed damage intensity of 15 percent. This noise level is a fairly “strong” amplitude of measurement

noise, and it seems unlikely that this amount would be observed in practice. What is valuable to note here is the rate at which the reliability improves as additional modal frequencies of the structure are considered.

V. SUMMARY AND CONCLUSION

The results of this study indicate that features such as spatial quantization and distribution of the imposed measurement noise do effect the reliability of the DLAC localization method. Identification model quantization, in this study, appears to significantly effect the reliability of the method if model ratios of less than M = 0.25 are implemented. In all cases, the reliability of the method appeared insensitive to the damage ratio, D. Characteristic distribution of the noise implemented to simulate "actual" modal parameters greatly affect the sensitivity of the DLAC metric after a threshold of 3 percent was crossed. In one case the reliability of the DLAC method was reduced the by nearly 50 percent, cf. (15 percent imposed error).Admittedly Messina, Jones, and Williams implemented their study on a slightly more complex structure, geometrically speaking. Thus, perhaps to truly understand the effects of the considerations taken in this study, Messina's structure should be re-analyzed under the same conditions. Such a comparison would be useful. In summary, implementing the Ld performance metric and a reasonable condition on which to base success, the DLAC procedure has been shown to be reliable for localization of single damage scenarios in a cantilever beam model.

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