STRUCTURAL HEALTH MONITORING

M.Padmakar Assistant professor, Vignan's Institute of Information Technology, Visakhapatnam- 530049,padmakarmaddala@gmail.com
Bheesetty Cherashmi Saranya[b], P.Kumar Eswara Parasuram[c], Rojeena Mathew [d]
P.Rakesh[d] UG Student, Vignan's Institute of Information Technology, Visakhapatnam- 530049
bhcherashmi@gmail.com: rgeorge@gitam.edu

INTRODUCTION:

Structural health monitoring is the process of adopting a damage identification approach for aerospace, civil, and mechanical engineering infrastructure (SHM). Bridges, buildings, dams, pipelines, aircraft, and ships, among other structures, are complex designed systems that secure the economic and industrial prosperity of society. Standardized building rules and design approaches have been developed to create structures that are safe for public usage. Structures are frequently subjected to high stress situations and severe environmental conditions that were not anticipated during design, resulting in long-term structural damage. The high expense of manpower and materials involved in a disaster necessitates having detailed knowledge about the structural health.Unfortunately, due to the intricate design of the buildings, as well as the stresses and environments they may be exposed to, this is not as simple as it appears. SHM is thus a ray of hope for the civil engineering community in terms of monitoring and detecting damage to structures. Because a problem of this complexity requires many hands to hold together and solve, ideas from mechanics, statistics, signal processing, and a variety of other domains are combined to make SHM.

This procedure entails taking periodic measurements of a structural or mechanical system over time, extracting damage-sensitive features from these data, and statistically analysing these features to estimate the current state of system health. The output of this procedure for long-term SHM is periodically updated information about the structure's ability to continue to fulfil its intended function in light of the inevitable ageing and damage accumulation caused by operational settings. SHM is utilised for quick condition screening in extreme events such as earthquakes or surprise blast loading.

Most damage detection methods work on the assumption that damage will change a system's stiffness, mass, or energy dissipation qualities, which will change the system's observed dynamic response. Although the fundamentals of damage detection appear simple, their implementation presents numerous technical obstacles. The most basic problem is that damage is often a local occurrence that may not have a major impact on a structure's lower frequency global response, which is typically monitored during vibration tests. In other words, this fundamental difficulty is identical to that encountered in many engineering domains where system response must be captured on scales of vastly variable lengths, and system modelling has proven difficult.Another significant challenge is that damage identification must often be done in an unsupervised learning mode. The term "unsupervised learning" refers to the absence of data from broken systems. Many practical obstacles connected with taking accurate and repeatable dynamic response measurements at a restricted number of places on complex buildings operating in harsh conditions add to these difficulties. Environmental and operational changes that affect the dynamic response of structures, such as temperature, moisture, and loading conditions, must also be considered. In fact, these changes can often conceal more subtle structural deterioration.

NEED AND SCOPE:

Almost every industry wants to detect harm to its products and production facilities as quickly as possible. The potential for life-safety and economic impact of this technology drives the need for these businesses to do some form of SHM. SHM technology is being investigated by aerospace businesses and government agencies for detecting damage to the space shuttle control surfaces masked by heatshields. Clearly, such damage detection has serious consequences for life safety. Furthermore, there are currently no quantitative ways for determining whether buildings are safe to reoccupy following a major earthquake. SHM could one day provide the technology to considerably reduce the uncertainty involved with post-earthquake damage assessments.The quick reoccupation of buildings, especially those linked with manufacturing, can greatly reduce the economic losses associated with major earthquakes. Finally, numerous components of our technical infrastructure are nearing or beyond their design life. Due to financial constraints, many civil, mechanical, and aerospace structures are being employed despite ageing and damage accumulation. As a result, the capacity to track the health of these buildings is becoming more critical.

The majority of current structural and mechanical system maintenance is time-based. For example, missiles are removed after a certain number of captive-carryhours on an aircraft's wing. SHM is the technology that will enable present time-based maintenance philosophies to evolve into more cost-effective condition-based maintenance philosophies. Condition-based maintenance is based on the idea that a sensor on the structure will monitor the system's response and alert the operator if damage has been identified. The benefits of such a mindset in terms of life safety and economics will only be achieved if the monitoring system offers enough warning so that corrective action can be implemented before the damage reaches a failure level.

Other reasons for employing SHM include the inability to use current technologies such as NDT in inaccessible regions. Furthermore, because they are local procedures, they require prior knowledge of the damage location. Furthermore, most civil structures have outlived their usefulness. This necessitates the use of a reliable monitoring system.

HISTORY OF SHM:

The SHM's first application was for condition monitoring. The rotating equipment application has almost exclusively used non-model based damage identification. Pattern recognition is used to identify displacement, velocity, and acceleration time histories (or spectra) often measured at a single location on the machinery's housing or shafts under normal operating conditions and start-up or shutdown transients. Often, pattern identification is done solely on the basis of a visual comparison of the spectra collected from the system at different periods. Databases have been created that allow specific forms of damage to be identified based on vibration signature elements. For rotating machinery systems, the approximate location of damage is usually known, making a single-channel fast Fourier transform analyzer sufficient for most periodic monitoring operations.Loose or damaged bearings, misaligned shafts, and chipped gear teeth are examples of common damage. Today, commercial software that is coupled with measurement hardware is sold to assist customers in applying this technology to their operating equipment in a methodical manner. The success of CM can be attributed to I the low operational and environmental variability associated with this type of monitoring, (ii) well-defined damage types that occur at known locations, (iii) large databases that include data from damaged systems, (iv) a well-established correlation between damage and features extracted from measured data, and (v) clear and quantifiable economic benefits that this technology can provide. These reasons have allowed SHM to move from a research topic to an industrial practise some decades ago, culminating in complete condition management systems like the US Navy's Integrated Condition Assessment System.

The oil industry spent a lot of time in the 1970s and 1980s developing vibration-based damage detection technologies for offshore sites. Because the damage site is unknown and the majority of the structure is not easily accessible for measurement, this damage identification problem is fundamentally different from that of rotating machinery. To overcome these challenges, the industry commonly used numerical models to simulate candidate damage scenarios, assess the changes in resonant frequencies created by these simulated changes, and connect these changes with those measured on a platform.Measurement difficulties caused by platform machine noise, instrumentation difficulties in hostile environments, changing mass caused by marine growth, varying fluid storage levels, temporal variability of foundation conditions, and the inability of wave motion to excite higher vibration modes were among the many practical issues encountered. These limitations made it difficult to adapt the technology, and efforts to further develop it for offshore platforms were mainly abandoned in the early 1980s.

During the building of the space shuttle in the late 1970s and early 1980s, the aerospace community began to investigate the application of vibration-based damage diagnosis. Current uses for the National Aeronautics and Space Administration's space station and future reusable launch vehicle concepts are being studied. The SMIS (shuttle modal inspection system) was created to detect fatigue damage in components including control surfaces, fuselage panels, and lifting surfaces. These sections were encased in a thermal protection system, rendering them inaccessible and thus unsuitable for traditional non-destructive assessment procedures. The SMIS has been successful in finding damaged thermal protection system components. Since 1987, all orbiter vehicles have been subjected to SMIS testing on a regular basis.The development of experimental/analytical methodologies targeted at determining damage to truss elements caused by space debris impact has been principally driven by space station applications. These methods work by comparing analytical models of the intact structure to measured modal parameters from both the undamaged and damaged structures. The damage is located and quantified using changes in stiffness indices as determined by the two model updates. The construction of a composite fuel tank for a reusable launch vehicle has inspired investigations of damage identification for composite materials since the mid-1990s. The failure processes for composite fuel tanks, such as delamination produced by debris hits, and the accompanying material response are very different from those for metallic structures. Furthermore, because the sensing systems must not supply a spark source, the composite fuel tank problem poses difficulties.SHM based on fibre optic sensing systems was developed in response to this challenge. In a second article in this theme issue, Boller&Buderath(2007) present a more extensive treatment of SHM applied to aeronautical structures.

Since the early 1980s, civil engineers have been researching vibration-based damage assessment of bridge structures and buildings. The key features utilised to diagnose deterioration in bridge constructions have been modal properties and quantities derived from these qualities, such as mode shape curvature and dynamic flexibility matrix indices. The bridge monitoring application has substantial hurdles due to environmental and operating state unpredictability. The structure's physical size also poses numerous practical obstacles for vibration-based damage assessment. Current research and commercial development of bridge SHMsystems is being driven by regulatory requirements in Asian countries, which demand bridge construction companies to certify their structural health on a regular basis. Brownjohn (2007) and Lynch (2007) contribute contributions to this theme issue that expand on the applicability of SHM to civil engineering infrastructure.The development of methods to optimally define the number and location of sensors; identification of features sensitive to small damage levels; the ability to discriminate changes in these features caused by damage from those caused by changing environmental and/or test conditions; the development of statistical methods to discriminate features from undamaged and damaged structures; and performance of comparative analyses are among the challenges in civil engineering applications. Many industries are now focusing on these themes, including defence, civil infrastructure, automotive, and semiconductor manufacturing, where multidisciplinary techniques are being employed to develop SHM and CM capabilities.

THE PROCESS OF SHM:

The SHM procedure is a little tricky in that the stage classification is not standardised. However, we can categorise it as follows.

Definition of the issue-

It's similar to operational evaluation. It entails answering a series of questions about the problem at hand as well as the solution we propose. The following are some possible questions:

1) What are the financial and/or life-safety motivations for conducting the monitoring?

2) How is damage to the monitored system defined?

3) What are the operational and environmental conditions in which the system to be monitored operates?

4) What are the constraints of data acquisition in an operational setting?

Operational assessment begins by defining the parameters of what will be monitored and how it will be done. This review begins by tailoring the damage detection procedure to features that are unique to the monitored system, as well as attempting to exploit unique features of the damage to be discovered.

Data Acquisition:

Excitation methods, sensor kinds, number and locations, and data acquisition/storage/transmittal gear are all part of the data gathering element of the SHMprocess. This procedure will be application-specific once again. These judgments will be heavily influenced by economic concerns. Another factor to consider is the frequency with which the data should be collected. Because data might be measured under a variety of settings, the ability to normalise the data is critical to the damage detection process. Data normalisation, in the context of SHM, is the act of distinguishing variations in sensor readings caused by damage from those generated by operational and environmental changes.Normalizing measured responses by measured inputs is one of the most used methods. When environmental or operational variability is a problem, it may be necessary to normalise the data in some way in order to compare data collected at similar points in the environmental or operational cycle. Variables in the data gathering process and the monitored system must be recognised and minimised to the greatest extent possible. Not all sources of unpredictability can be removed in general. As a result, adequate measurements must be taken so that these sources may be statistically quantified. Variability can be caused by changes in the environment and test settings, as well as changes in the data reduction process and inconsistencies between units.

The process of selecting data to pass on to or reject from the feature selection process is known as data purification. The information gathered by persons directly involved in the data collecting is frequently used in the data purification process. An inspection of the test set-up, for example, may reveal that a sensor was carelessly attached, and thus this set of data or the data from that particular sensor may be selected eliminated from the feature selection process based on the judgement of the individuals performing themeasurement. Filtering and resampling are examples of signal processing techniques that can be thought of as data purification procedures.

Feature extraction:

The discovery of data features that allow one to distinguish between the undamaged and damaged structure is the section of the SHM process that receives the most attention in the technicalliterature. As a result, the feature extraction section of SHM is the subject of many articles in this theme issue (Fassois&Sakellariou 2007; Friswell 2007; Mal et al. 2007; Staszewski& Robertson 2007). The data is condensed as part of this feature selection procedure. Damage detection's best characteristics are, once again, application specific. Correlating measurable system response characteristics, such as vibration amplitude or frequency, with first-hand observations of the degrading system is one of the most used feature extraction approaches.Another way to build features for damage detection is to introduce engineered defects into systems that are similar to those seen in real-world operating settings and gain an initial understanding of the parameters that are sensitive to the expected damage. The defective system can also be used to verify that the diagnostic measures are sensitive enough to distinguish between undamaged and damaged system features. In this procedure, analytical methods such as experimentally validated finite-element models can be quite useful. Analytical tools are frequently used to conduct numerical experiments in which faults are introduced using computer simulation. Damage accumulation testing, which involves submitting important structural components of the system under investigation to actual loading conditions, can also be utilised to find relevant features.To accelerate the accumulation of specific types of damage, this method may include induced-damage testing, fatigue testing, corrosion growth, or temperature cycling. As indicated above, insight into the appropriate traits can be achieved from a variety of analytical and experimental research, and is usually the product of a combination of these studies.

Damage Detection:

A robust damage detection technique should be able to detect damage at an early stage, locate the damage within the sensor resolution utilised, offer an estimate of the degree of the damage, and anticipate the structure's remaining usable life. The procedure should also be easy to automate. The technique should not rely on the user's engineering judgement or an analytical model of the structure to the greatest extent practicable. A less ambitious but more feasible goal would be to establish a system that has all of the aforementioned properties but uses an initial measurement of an intact structure as the baseline for subsequent measured response comparisons. Furthermore, the approaches must be able to account for operational constraints.For instance, most damage-identification methods documented in the technical literature to far make the assumption that the structure's mass does not vary significantly as a result of the damage. However, there are some constructions, such as offshore oil platforms, where this assumption is incorrect. Another significant aspect of damage-identification approaches, particularly those that employ prior models, is their ability to distinguish between modeldata mismatches generated by modelling mistakes and those induced by structural damage.

Damage to a structure can be classed as either linear or nonlinear. A lineardamage condition occurs when an initially linear-elastic structure remains linear-elastic after being damaged. Variations in the geometry and/or material properties of the structure cause changes in modal properties, but the structural response can still be represented using a linear equation of motion. Nonlinear damage occurs when a linear-elastic structure acts in an anonlinear manner after being damaged. The creation of a fatigue fracture that then opens and closes under normal operating vibrations is an example of nonlinear damage. Other examples include rattling connections and material behaviour that is nonlinear.Both of these general categories of damage will require a powerful damage detection mechanism. The majority of the publications included in this review are concerned with linear damage detection solely.

According to Rytter(1993), a categorization system for damage-identification methods defines four degrees of damage identification:

Level 1: Determination that the structure is damaged.

Level 2: Determination of the damage's geometric location

Level 3: Calculation of seventy percent of the damage

Level 4: Prediction of the structure's remaining service life

The features and methods utilised for damage detection are as follows:

A. Frequency shifts: Damage causes a change in the frequency of vibration, which is referred to as a 'frequency shift.' The impact of damage on frequency and its identification is outside the scope of this report. To summarise, frequency is a fast approach to detect damage but not to find it. It's impossible to find it based on frequency shifts because frequency is a worldwide phenomenon. It is mostly used to detect damage before using other ways to discover and quantify it.

B. Forward and Inverse methods:

The forward problem, which is commonly classified as Level 1 damage detection, entails computing frequency shifts from a known type of damage. Typically, the damage is mathematically modelled, and then the measured and projected frequencies are compared to assess the damage. Calculating damage parameters, such as fracture length and/or position, from frequency shifts is the inverse problem, which is often Level 2 or Level 3 damage detection. A FEM model is sometimes used to forecast frequency shifts for various damage intensities, and the results are compared to the observed frequency. Genetic algorithms, particle swarm optimization, and differential equations are commonly used.

Mode Shape changes:

Mode shapes are connected to damage-induced alterations as much as they are to frequency. The use of mode shapes with or without a FEM model, as well as comparisons with healthy cases utilising certain criteria, aids in the diagnosis of Level 2 damage. To compare the mode shapes of two states of a structure, the Modal Assurance criteria or other similar metrics are utilised. These, on the other hand, are thought to be incorrect and overly susceptible to environmental changes.

A. Statistics Based:

To discover anomalies in the system, least square metrics, principal component analysis, proper orthogonal decomposition, and other statistics-based methods are applied. In some circumstances, signal processing methods such as HHT and wavelet analysis are applied. Such approaches have various advantages, including multi-level analysis, output-only damage detection, and so on.

Damage Prognosis(DP):

DP seeks to estimate system performance by assessing the system's existing damage condition (i.e. SHM), projecting future loading scenarios for that system, and predicting the system's remaining usable life using simulation and historical experience. The successful development of aDP capability will necessitate the further development and integration of a variety of technology areas, including measurement/processing/telemetry hardware as well as a variety of deterministic and probabilistic predictive modelling capabilities, as well as the ability to quantify the uncertainty in these predictions. The DP problem's diverse and demanding nature, its current embryonic state of development, and its enormous potential for life-safety and economic benefits qualifies it as a "grandchallenge" topic for engineers in the twenty-first century.

SENSOR FAULT DIAGNOSIS:

Because the entire SHM is reliant on the accuracy of sensors, it is critical to ensure that the sensors are in good working order. To detect and categorise faults, various algorithms have been developed, including state space, Arma models, PCA, and others. There are also methods for recovering lost sensors. The majority of the methods are based on statistics. Faults are divided into two categories: additive and multiplicative faults.

When a sensor exhibits "a non-permitted divergence from the distinctive qualities," it is deemed defective. Bias, drift, full failure, and precision degradation are all examples of this aberration. A sensor reading is biassed if it departs from the real value by a consistent amount. The term "drift" was coined to describe a situation in which the discrepancy between sensorreading and real value grows linearly over time. Complete failure occurs when the sensor reading remains constant despite changes in the actual value. Another problem that is believed to be infrequent is gain fault. It indicates that the sensor's variance has grown. Precision deterioration occurs when a sensor reading is linked with an excessive amount of white noise.

ROAD AHEAD-CHALLENGES IN SHM:

The preceding discussion should have convinced you that SHM is not simple. As a result, interest in the field has grown. The most specialised area is damage prognosis, which requires a great deal of attention. Application-specific algorithms, such as those for composites, will be created. Existing damage detection methods must be made both accurate and quick. Furthermore, no one algorithm can be used everywhere. Many algorithms are also ecologically conscious. Aside from the aforementioned, the use of new materials necessitates the application of newer algorithms.

Not only that, but the domains of data storage, sensor positioning, sensor production, and so on also require further investigation. The following are the general outlines of SHM research.

SHM IN INDIA:

SHM in India is still in its infancy. There are very few applications and significant studies. SHM has recently seen a surge in activity. A company called Cowi a/s keeps an eye on the Naini bridge that spans the Yamuna. A SHM system for the 'Nishant' unmanned aircraft was developed by DRDO and NAL in 2010. A comprehensive SHM system for civil structures is being developed by CSIRlab SERC in Chennai. Many organisations also hold conferences and workshops in order to generate interest and investment in SHM.

CONCLUSION:

As can be seen, SHM is a multidisciplinary issue that necessitates unselfish collaboration among many study groups. Government agencies must also demonstrate vision and boldness in their long-term investments in SHM. A concerted effort by the entire civil engineering community can benefit society greatly. This report merely attempted to provide an overview of the entire field. Further investigation would disclose its complexities, benefits, and obstacles that SHM faces. In terms of SHM research, one expects that the next decade will be a game changer.

REFERENCES:

1. Doebling S. et al, 1996,'*Damage Identification and Health Monitoring of Structural and Mechanical Systems from Changes in Their Vibration Characteristics*', Los Alamos Laboratory.
2. Farrar C.R. and Worden K., 2007, '*An introduction to Structural Health Monitoring',* Phil. Trans. R. Soc. A 2007 ,pp.303-315.
3. Sohn H. et al, 2004, '*A Review of Structural Health Monitoring Literature: 1996–2001*', Los Alamos Laboratory.
4. *Lynch J P et al, 2006, 'A Summary Review of Wireless sensors and Sensor Networks for Structural Health Monitoring'.*
5. Mosallaei et al., *'Sensor Fault Detection using Adaptive Modified Extended Kalman Filter Based on Data Fusion Technique'.*
6. Karbhari, VM and Ansari F*,' Structural Health Monitoring of civil infrastructure system'*, CRC Press.
7. Friswell M, 2007,*'Damage identification using inverse methods'*, Phil.R.Trans.A.
8. Fan, 2011, '*Vibration-based Damage Identification Methods: A Review and Comparative Study, Structural health monitoring*', Sage Publishers.
9. Salawu, 1997,*'Detection of structural changes through changes in frequency'*, Engineering structures.

Kerschen et al, 2005,' *Sensor validation using PCA*', Smart. Mat. Struc

10. Srinivas K, Vijaya SK, Jagadeeswari K. Concrete with ceramic and granite waste as coarse aggregate. Materials Today: Proceedings. 2020 Aug 29.
11. Priyanka ML, Padmakar M, Barhmaiah B. Establishing the need for rural road development using QGIS and its estimation. Materials Today: Proceedings. 2020 Sep 12.
12. Padmakar M, Barhmaiah B, Priyanka ML. Characteristic compressive strength of a geo polymer concrete. Materials Today: Proceedings. 2020 Sep 20.
13. George R, Patel IB, Rathod KT. Growth and photoluminescence study of nickel sulfate doped Zinc tris-Thiourea Sulfate (ZTS) crystal. Materials Today: Proceedings. 2020 Sep 11.
14. M.PADMAKAR, BRAMAIAH.B, SRINIVAS.K, LAL MOHIDDIN .SK. MIX DESIGN FOR RIGID PAVEMENT BY USING RECYCLED AGGREGATE WITH THE ADDITION OF ADMIXTURE. JCR. (2020), 7(13): 2187-2193. doi:10.31838/jcr.07.13.340
15. KARRI SRINIVAS, M.PADMAKAR, B.BARHMAIAH, SATHI KRANTHI VIJAYA. EFFECT OF

ALKALINE ACTIVATORS ON STRENGTH PROPERTIES OF METAKAOLIN AND FLY ASH BASED GEOPOLYMER CONCRETE. JCR. (2020), 7(13): 2194-2204. doi:10.31838/jcr.07.13.341

16. Karri Srinivas, Sathi Kranthi Vijaya, Kalla Jagadeeswari, Shaik Lal Mohiddin, Assessment of young's modulus of alkali activated ground granulated blast-furnace slag based geopolymer concrete with different mix proportions, Materials Today: Proceedings, 2021,ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2020.10.765.

17. BORIGARLA BARHMAIAH, K.SRINIVAS, M.PADMAKAR , LAL MOHIDDIN .SK. PEAK HOUR ANALASIS AND EFFECT OF TRAFFIC COMPOSITION ON CAPACITY OF ARTERIAL ROADS. JCR. (2020), 7(13): 2205-2213. doi:10.31838/jcr.07.13.342

18. Maddala P. Pushover analysis of steel frames (Doctoral dissertation).

19. Vummadisetti S, Singh SB. Buckling and postbuckling response of hybrid composite plates under uniaxial compressive loading. Journal of Building Engineering. 2020 Jan 1;27:101002.

20. Singh SB, Vummadisetti S, Chawla H. Development and characterisation of novel functionally graded hybrid of carbon-glass fibres. International Journal of Materials Engineering Innovation. 2020;11(3):212-43.

21. Vummadisetti S, Singh SB. Postbuckling response of functionally graded hybrid plates with cutouts under in-plane shear load. Journal of Building Engineering.;33:101530.

22. S. Vummadisetti, Singh, S. B. "Boundary condition effects on postbuckling response of functionally graded hybrid composite plates." J. Struct. Eng. SERC 47, no. 4 (2020): 1-17.
23. [19] Study of activation energy for KDP crystals in etchants with citric and tartaric acids
24. R George, IB Patel, P Maddala, S Karri
25. Materials Today: Proceedings
26. [20] Growth studies for calcium phosphates (Brushite) crystals in gel method
27. R George, IB Patel
28. ACTA CIENCIA INDICA PHYSICS 28 (3), 137-140
29. [21] STUDY OF ACTIVATION ENERGY FOR KDP AND DOPED KDP SINGLE CRYSTALS USING THERMO GRAVIMETRIC ANALYSIS
30. R GEORGE, IB PATEL, AM SHAH

