Application of Machine Learning with Impedance Based Techniques for Structural Health Monitoring of Civil Infrastructure

Zaheer Ahmed, Jaffar Syed Mohamed Ali, Mohammed Rafeeq, Meftah Hrairi

Abstract— Increased attentiveness on the environmental and effects of aging, deterioration and extreme events on civil infrastructure has created the need for more advanced damage detection tools and structural health monitoring (SHM). Today, these tasks are performed by signal processing, visual inspection techniques along with traditional well known impedance based health monitoring EMI technique. New research areas have been explored that improves damage detection at incipient stage and when the damage is substantial. Addressing these issues at early age prevents catastrophe situation for the safety of human lives. To improve the existing damage detection newly developed techniques in conjugation with EMI innovative new sensors, signal processing and soft computing techniques are discussed in details this paper. The advanced techniques (soft computing, signal processing, visual based, embedded IOT) are employed as a global method in prediction, to identify, locate, optimize, the damage area and deterioration. The amount and severity, multiple cracks on civil infrastructure like concrete and RC structures (beams and bridges) using above techniques along with EMI technique and use of PZT transducer.

In addition to survey advanced innovative signal processing, machine learning techniques civil infrastructure connected to IOT that can make infrastructure smart and increases its efficiency that is aimed at socioeconomic, environmental and sustainable development.

Keywords—SHM, EMI, PZT, soft computing, IOT, Concrete, RC bridges, RC Beam

I. INTRODUCTION

Civil structures that consist of concrete structures, buildings, bridges etc. deteriorate with age, conditions, environment etc. Monitoring of these structures constantly and at right moment is critical and essential for safety and wellbeing of all. The integrity of these structures needs to evaluate in terms of usage and age, and how it can withstand on perilous situations such as earthquakes, landslides and other high forces. Health monitoring of structures is principally, finding and tracking structural integrity, evaluating the amount and nature of the damage [1].

The traditional methods do not give complete and accurate information on the damage within the structure. These methods have been used only to detect damage present or not, it does not provide nature, amount, multiplicity and criticality of the damage. Damage detection of concrete and reinforced bridges is new area for the researches to work on.

The prospective tool emerged for self-diagnosis and damaged detection is impedance based technique that utilizes a piezoelectric ceramic material (PZT) [2]. To monitor the variation in structure, mechanical impedance high frequency excitations are used in this technique. In impedance based damage detection technique a piezoelectric transducer is attached to the host structure and the electric point impedance is principally tracked to diagnose and monitor the damage in the structure. The change in electric point impedance of piezoelectric transducer is due to physical variations in structure.

In the area of civil infrastructure, specifically in the applications of concrete structures and RC bridges [3], PZT impedance based technique have been found to be very successful in the identification, damage detection and deterioration monitoring of these structures.

Internet of things uses intelligent sensors connected to the network; these sensors create a communication pattern with all the objects of our life and work [4]. The technology of IOT has extended to civil infrastructure and these smart civil structures connected IOT would revolutionize the world around us.an illustration of PZT transducer usage for civil infrastructure connected IOT is discussed [5].

IOT is internet of things where objects are connected to the internet; these objects communicate with other and can be tracked etc.

Civil infrastructure such as bridges, roads, pipelines, roads etc. and the dynamic activities at these infrastructural points create substantial amount of valuable data. The information collection from these civil structures are important for safety, serviceability, durability and energy efficiency, which in turn have substantial impact not only on infrastructure but also on economic development, environment and quality of life. If the information collected from these structures are gathered in a smarter way, manipulated in uniform format and transferred between the other structures/objects in sensory and intelligent manner, this makes infrastructure in IOT contribute prominently to IOT connected infrastructure to follow optimal routes.

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The consequences of environment are lessening and compensated, with emerging smart civil infrastructure and loading on these structure can be reduced with structural health monitoring techniques.

Civil infrastructure connected to IOT smartly can improve the situation, as great concern mounting with this structure is durability, this is the reason NDT and evaluation is discussed and studies among the researchers [5].

IOT uses smart objects with its central or integral part called BRAIN, to detect damage and weakening of civil infrastructure at early stages, the damage or deterioration in the structure can be because of several reasons and factors.

IOT networks can be extended to prevent accident, to be prepared in advance for catastrophic situation. IOT networks with its BRAIN instruction can be even used to repair damages of infrastructure by themselves [6]. The exceptional feature closed loop control and feedback make them evident choice for monitoring of health of civil infrastructure. In the research area of SHM of civil structure IOT connected devices such as Piezoelectric accelerometer, LVDT, fiber optic etc. are frequently used. However, for civil infrastructure new sensors and actuators are being developed that can be connected to IOT network [7]. The sensor PZT is specifically discussed in this paper.

The sustainability and durability of civil infrastructure can be greatly increased with IOT Network.

This paper highlights new research directions and envisions researches thought and exploration on technologies for SHM connected to internet for sustainable urban development.

II. EMI TECHNIQUE FOR CIVIL STRUCTURE

A. EMI and PZT

NDT for concrete structures [8] is at developing stage, however the NDT are expensive, tedious and less reliable, so the need is to have built-in diagnosis for continuously monitoring of concrete structures when they are in operation. Parametric techniques because of the ability to identify and detect one type of damage in civil structures NDT till date remains to one of the vital part for health monitoring of civil structures.

The coupling effect between host structure and piezoelectric transducer patch is used for impedance based SHM. 1-D electro mechanical system is shown in figure to conceptually describe the coupling effect[9].

While implementing EMI technique, a PZT is attached to the host structure and a patch acts as an actuator and/or sensors. It is excited by electrical voltage and connected to host structure, the real and imaginary parts of electro mechanical admittance signature is measured by impedance analyser.

PZT is new intelligent material used in impedance based EMI technique, The representation of PZT patch is a short circuit impedance and effects of mass, stiffness, damping and other boundary conditions are denoted by a driving point mechanical impedance.

The studies Sun et al [11], Park et al. [12] and Chaudhry et al. [10]reveal and results validate that EMI technology is effective in motoring the conditions various structures. Concrete strength is also monitored using EMI technique, also the technique is used during the curing process of concrete as indicator for concrete strength evaluation was demonstrated, using regular shifts of impedance spectra in recent studies. The extensive investigation on corrosion damage in RC structures and steel, and sensing range of PZT transducer are new avenues of research.

In large prototype RC structures damage diagnosis and failure predication in shear RC beams was carried out using wireless miniature impedance chip and dual PZT transducer.

Furthermore, PZT transducer have been widely explored to monitor critical issues of in-situ stress of structures. Particularly EMI techniques is employed to study the monitoring of compression stress or structural tension.

Zhu ans scalea [13] presented characteristics of conductance signatures responding to axial load and the dynamic stiffness in the structures. Lim and soh [14] investigated the influence of axial load on the admittance signatures with fixed boundary conditions and they presented numerical, analytical and experimental results, the results shows right shift of conductance signature to cause because of compression stress and axial load. These features were also present when compression test was performed on test on concrete cube.

Also in the literature the main focus was on substantial effect of boundary conditions on complex dynamic stiffness when it is derived. The concentration of these validation on metal structural stress leaves a gap to evaluate the same for NON metal structural stress.

Evaluation of compression stress/structural tension using EMA signatures are still required that eliminates the limitations discussed above.

The resulting effect of dynamics between host structure and PZT is represented [15] by integrated electro mechanical impedance and since PZT is electrically powered by current or voltage, the overall system can be represented by electrical impedance.

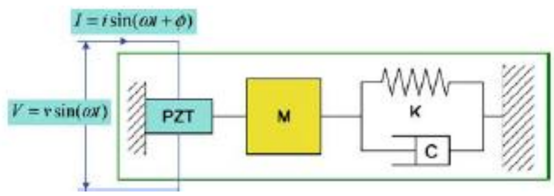


Fig.1.1-Dimentional Electro-mechanical impedance system

$$Y(\omega) = i\omega a\left(\varepsilon_{33}^T(1-i\delta) - \frac{Z_{S(\omega)}}{Z_S(\omega)+Z_a(\omega)} d_{3x}^2 \bar{Y}_{xx}^E \right. \quad (1)$$

$Z(\omega) =$
$\{ i\omega C\left(1-K_p^2\right) \times$
1+Kp2
1+vJ1φa1−KP2φaJ0φ−1−vJ1φa−Xω1+VJ1φa−1
(2)

The 1-D model introduced here is as shown in Equation (1), which shows that the electrical admittance Y(w) (inverse of impedance) of the PZT is direct relation with the mechanical impedance of the structure Zs(w). Therefore, any changes in the properties of the structure can be recognized by checking the changes in the electrical impedance of the connected PZT transducer.

Also in equation variables used are the input frequency, dielectric constant, geometric constant, coupling constant a loss tangent and Youngs modulus.

B. EMI and FEM Modeling

The limitations of analytical models have been overcome by FE models, these models are excellent substitute to the analytical models. In an engineering problem where the requirement is to closely approximate, and there is unavailability of analytical models, Finite element models assist the analyst with the numerical evaluation to such problems.

In this section some of studies are reviewed on use of FE models in the area of smart Piezoelectric SHM, the FE models were employed in both the techniques of smart piezoelectric namely electromechanical impedance and wave propagation. The Coupled FE and conventional FE are compared in this study.

The studies show to model EMI technique; very beneficial tool finite element method is being utilized till recent times. [16,18]. Liu and Giurgiutiu [17] for both 1-D beam structures with installed PWAS and free piezoelectric wafer active sensors (PWAS), finite element method (FEM) is applied to the EMI techniques for the investigation.

They experimented both the approaches to the FEM simulation of the 1-D beam-PWAS system, i.e. direct modelling of the structure- PWAS interaction using 3-D coupled field elements and 2-D analysis using shell elements without electro-mechanical coupling. The clear indication is Admittance signatures given by the coupled field 3-D simulation were nearer to the experimental results, on Comparison of results of both the approaches.

Lim and Soh [14] established a proof-of-concept semi-analytical damage model which incorporates elastic fracture mechanics theory and linear finite element (FE) simulation into the EMI technique. EMI technique was able to identify fatigue crack propagation, lab-sized 1-D beam structure were used on the Experiment, and estimation of remaining life of the structure can be done using the damage model.

Park et al. [11] conducted experiment for damage monitoring using multiple PZT transducers. For the verification of experimental study FE simulations were utilized, measurement of impedance signatures and concrete beam with induced progressive surface damage was carried out.

The predictions of damage with Finite Element simulation has shown consistent trend in the investigation carried out , in terms of the variations in the impedance signatures.

Recently the works on concrete curing monitoring using the EMI technique, also recent works on the newly developed technique smart probe are found to be limited.

More accuracy was obtained for 3-D coupled field finite element method for EMI simulation in the review of Existing studies [19]. In author [20] has attempted new technique Smart Probe-based technique.to monitor cementitious materials along with 3-D coupled field FE simulation.

A systematic examination dependent on limited component (FE) models is done to check the legitimacy of the trial result. Also, numerous (shear and flexural) breaks brought about in a strengthened cement (RC) pillar under a third point twisting test are checked constantly by utilizing a sensor cluster framework made out of the PZT patches. In this examination, a root mean square deviation (RMSD) in the impedance mark of the PZT patches is utilized as a harm pointer. So as to approve the above trial results, a systematic examination dependent on limited component (FE) models was done. A business programming, ANSYS6.0, was utilized to demonstrate the brilliant auxiliary framework (Concrete bar with PZT fix) and to figure the electro-mechanical impedance of the framework. This investigative examination was performed just at the low recurrence go (20 to 25 kHz) comparing to the horizontal methods of the PZT fix. To figure the electro-mechanical impedance, a coupled field examination, which takes the communication between at least two orders of designing (i.e., a piezoelectric investigation handles the association between the basic and electric fields) into record, was used [13]. The FE display for the plain solid shaft was combined with the PZT attached.

C. Concrete Structures and Cementious Material

In the civil infrastructure the most important and integral material considered for construction of structure is Concrete, because of the strength it gets through its ingredients mainly cement and water. The process hydration of cement increases the strength of concrete, that is chemical reaction between water and cement particles.

Due the high alkaline nature of concrete, the effect of corrosion in minimal on the steel reinforcement and hence concrete is used to protect reinforcement steel material from getting corroded. Also the penetration of chloride ions and carcondioxide which are inducing agents of corrosion reduces to great extend because of concrete that has low water –cement ratio i.e. it has low permeability Thus rightly cured and well compacted concrete is used to prevent corrosion.

Concrete is a heterogeneous and isotropic material, which makes its mathematical analysis difficult. Concrete structures in specific like nuclear stations, dams, bridges etc. needs to be constantly monitored because the failure of such system may lead to disastrous outcome. Manual inspection methods are costly and requires on site involvement. The challenging area for the researchers is the issue in using EMI technique to large concrete structures [21] as Compared with other structures, the vibrational characteristics of composite panel bonded to solid concrete is different. health monitoring (damage detection, delamination, identify and localize disbonds) of concrete structure repaired and reinforced with composite materials using PZT transducer is new research area and authors verified and got results for the same.

The research is under laboratory environment, before put into application, the PZT transducer's durability should be investigated when the systems is exposed different environmental effects and dynamic loading conditions. In any of the civil structures the steps or analysis using EMI technique to identify, detect and determining the severity of damage using damage index, the figure shows the flow of detection mechanism using EMI technique.

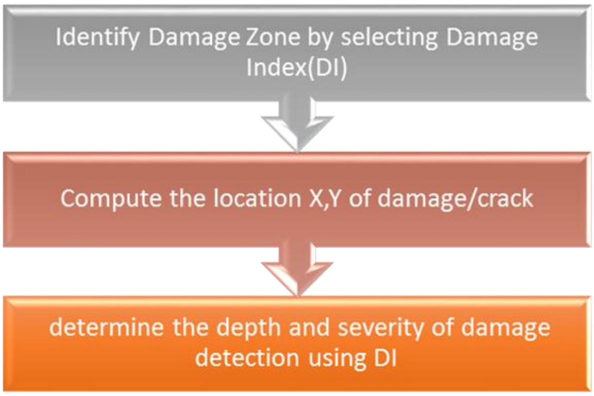


Fig 2. Steps in damage detection

Another issue of rebar corrosion is discussed while using PZT, the problem of rebar corrosion rarely occurs during its design life because of the high resistive property of concrete, this limits corrosion rate of the rebar by reducing the flow of electric current. practically the situation is not always attained due to various reasons, so in RC structures common issue faced is due to rebar corrosion. In last few years, many corrosion assessment and monitoring techniques have been established. Author[22] discusses the results of the experimental work, to assess corrosion development using PZT patches surface bonded on rebars, author have used five concrete cubes with embedded rebars and has carried out accelerated corrosion test. Based on the analysed data an empirical corrosion quantification model has been formulated.

D. RC Beam and RC Bridges

A systematic examination dependent on limited component (FE) models is done to check the validity of the trial result. Also, numerous (shear and flexural) breaks brought about in a strengthened cement (RC) pillar under a third point twisting test are checked constantly by utilizing a sensor cluster framework made out of the PZT patches. In this examination, a root mean square deviation (RMSD) in the impedance mark of the PZT patches is utilized as a harm pointer. So as to approve the above trial results, a systematic examination dependent on limited component (FE) models was done. A business programming, ANSYS6.0, was utilized to demonstrate the brilliant auxiliary framework (Concrete bar with PZT fix) and to figure the electro-mechanical impedance of the framework. This investigative examination was performed just at the low recurrence go (20 to 25 kHz) comparing to the horizontal methods of the PZT fix. To figure the electro-mechanical impedance, a coupled field examination, which takes the communication between at least two orders of designing (i.e., a piezoelectric investigation handles the association between the basic and electric fields) into record, was used [13]. The FE display for the plain solid shaft was combined with the PZT fix demonstrate for the six harm cases (from A to F), as appeared in Fig. 7.

E. Statistical Metrics for Damage Quantification

The severity of damage can be quantified once impedance signature is assimilated, the changes in impedance Signature is a measure of change in the structural properties (e.g., because of damage, changes in temperature, etc.), with larger changes subjected to bigger damage.

The quantitative assessment of the Signatures is done generally using these 4 different statistical equations [25]. They are Root Mean Square Deviation (RMSD), Covariance (Cov), Mean absolute percentage deviation (MAPD), and correlation coefficient (CC), and are signified by the Equations (3)–(6).

Here, Re (Zk)i represents the reference impedance signature (real part) and Re(Zk)j represents signature (imaginary part). N is number of impedance signatures, with the symbols of Z are mean values and sZ is representing standard deviation.

$$RMSD = \left(\sum_{K=1}^{N}\left[Re(Z_k)_j - Re(Z_k)_i\right]^2 / \sum_{k=1}^{N}[Re(Z_k)_i]^2\right)^{1/2} \quad (3)$$

$$MAPD = \frac{1}{N}\sum_{k=1}^{N} \left|\left[Re(Z_K)_j - Re(Z_k)_i\right]/ Re(Z_k)_i\right| \quad (4)$$

$$COV = \frac{1}{N}\sum_{k=1}^{N}\left[Re(Z_K)_j - Re(\overline{Z})_j\right]\cdot \left[Re(Z_K)_i - Re(\overline{Z})_i\right] \quad (5)$$

$$CC = \frac{1}{N\sigma Z_j \sigma Z_i}\sum_{k=1}^{N}\left[Re(Z_K)_j - Re(\overline{Z})_j\right]\cdot\left[Re(Z_K)_i - ReZi \right. \quad (6)$$

Till date, most of the studies shows that these 4 statistical equation have been used in the investigation of EMI technique, amongst which RMSD is being utilized the most. In the investigation of Tseng and Naidu [24] execution of the 4 diverse measurable measurements, and it was found through the trials that covariance and CC were increasingly suitable for recognizing the expansion in harm estimate at a fixed area, while RMSD and MAPD were progressively proper for finding and describing the development of harm.

In the examination by Tawie and Lee [26] used three factual measurements (RMSD, MAPD and CC. To screen solid relieving and quality addition for as long as 28 days utilizing the EMI method. To a solid example of size 150 mm3 a PZT transducer was connected where impedance was estimated on days 7, 14 and 28. From the examination, the creators found that MAPD associated superior to both the RMSD and CC measurements.

The EMI system examined by Xu and Jiang [28] was completed to screen jolt slackening of a solid steel composite support by using MAPD, RMSD, CV and CCD. To the upper rib of the steel support and the solid section number of PZT transducers were surface-fortified, where jolt slackening was recognized by checking impedance marks.

Hu et al. [27] proposed another harm list by the creators, Ry/Rx to take a shot at discovery of harm on a solid section (500 mm _ 300 mm _ 50 mm) utilizing CCD and RMSD. The outcomes demonstrated that the recurrence go beneath 100 kHz performed superior to anything ranges over this recurrence run for harm distinguishing proof, with the creators affirming that the proposed new harm file indicated better outcomes.

Wandowski et al. [29] utilized Chessboard Distance (CB), a measurable metric other than the previously mentioned four conditions, to assess the execution of the EMI strategy on composite structures exposed to harm. Here, the creators found that CB performed superior to RMSD as CB values expanded, with an expanded dimension of harm at various temperatures.

Other factual measurements for breaking down the impedance marks incorporate normal square deviation (ASD), joined mechanical impedance (UMI), circle harm list (EDI) and others, and new measurements in the field of the EMI procedure are being proposed by different analysts [30– 31]. Nonetheless, the utilization of a solitary kind of metric for EMI based harm recognition has a few restrictions, as little harm at short proximity to the PZT transducer can display indistinguishable outcomes from bigger harm further away.

One way to deal with conquering this issue could be to join a few factual measurements to build the capability of effectively distinguishing and finding auxiliary harm. The prediction can also be done by newly proposed damage index Ry/Rx, that keep track of the changes in depth.

The newly proposed damage index Ry/Rx increases as the amount of damage increases. It can monitor the amount of damage of reinforced concrete slabs as well.[32]

To localize disbands, detect and delamination of advanced reinforced concrete structures an array of PZT transducers attached to host structure are employed

Smart probe is modified PZT transducer, smart probe is prepared with known mechanical properties and geometry by surface bonding of transducer on Aluminum beam, smart probe is prepared to eliminate the limitation of PZT transducer when directly attached to host structure in the traditional EMI technique. The smart probe is found to be better in Comparison with conventional EMI technique.

III. SOFT COMPUTING TECHNIQUES FOR SHM & RESULTS

New innovative techniques are being used for SHM of civil structures with newly developed sensors, sensor networks, signal processing and control theory for identifying and locating damage in the structure. Imaging and pattern recognition are used in novel methods to monitor cracks in the structure. To locate and level of damage Pattern recognition used.

A. ANN

To determine damage location, its size of the target structure and its remaining life are ultimate objectives of SHM.

Many authors have studies for different size and locations of damage, impedance signature differs in EMI technique. Artificial neural network (ANN) is widely used technique for locating here in this case damage and many studies have been carried out with EMI and ANN incorporated together for locating the damage. When an artificial neural network is applied the EMI, to successfully detect damage a large quantity of training set is required for the algorithm.

Several of the ANN techniques can be viewed in giurgiutiu. et al. [33] ,in which authors have employed EMI technique to aluminium Alloy based circular plates of dimension 100mm diameter and thickness of 1.6mm of the plate. For the above study PNN with a feature extraction algorithm was used. For the damage identification Min.et al have used multilayer feed forward with back propagation algorithm in combination with EMI technique, experimental works on box girder bridge and lab scale pipe structure exposed to crack damages and loose bolts for the evaluation of proposed technique.

The author has carried out work using PNN and fuzzy cluster analysis method for the classification of two different types of damages (rivet losses and cracks).

ANN with EMI techniques is also used for predication and determining strength of concrete structures during the curing process by constantly monitoring it for 28 days.

For ANN algorithm curing time, curing temperature, water cement ration, CC value and maturity are used for training.

The ANN model proposed by the author has given negligible error and estimates strength of prepared concrete specimen shown in the figure 4.

The traditional statistical metrics like MAPD, CC, covariance and RMSD are in sufficient to locate, identify and quantify the kind of damage the structure has undergone. Thus the trend of combine usage of ANN and EMI shows damages can be located, identified and quantified more effectively.

B. Particle Swarm Optimization

To solve many optimization problems, the authors Kennedy and Eberhart have introduced started particle swarm optimization. IN particle swarm optimization method every particle travel in search area with a velocity in accordance with its own previous best solution and its group best solution.

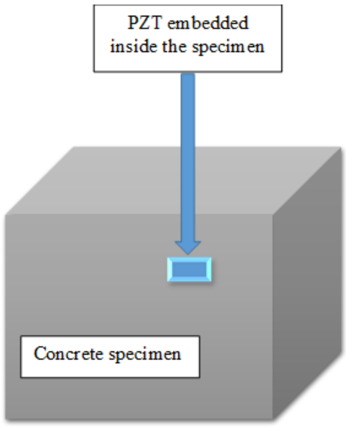
Suppose in a colony there are n particles in D-dimensional searching area. The ith particle

Locates at Xi = (xi1,xi2, . . . ,xiD). (i = 1, 2, . . .,n) in the searching space. By placing particles positins into a chosen objective function its fitness can be determined.

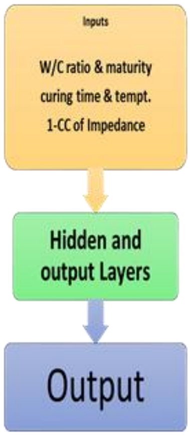
With the comparison of fitness of particles, the best position of colony Pg=(pg1,pg2, . . . ,pgD) and The best position of the ith particle presented as Pi=(pi1,pi2, . . . ,piD), can be determined.

Table 1. Overview of signal processing and soft computing techniques for structural health monitoring

Author	Technique	Method	Application
Girurgiutiu and kropes-Huges[34]	Artificial Neural Network(ANN)	Probabalistic Algorithm Neural Network was applied with a feature extraction algorithm along with EMI technique for the damage detection.	In the identification of damage location, size of the damage and service life of the host structure.
Zhang et al.[33]	Particle Swarm Optimization(PSO)	Damage parameters are determined from the variations in admittance spectra produced by the presence of the damage.	To determine damage style and different damage parameters.
Gu, H., et al.[35]	Fuzzy Logic(FL)	In the Fuzzy logic system samples are trained to correlate the harmonic amplitude with the concrete strength. Fuzzy logic is applied piezoelectric-based monitoring method.	At early age of concrete structure in the detection of damage, fuzzy logic is very productive.
Song, G., et al.[36]	Wavelet Analysis(WP)	WP analysis is utilized to break down the recorded sensor signals. A damage index is created based on the wavelet packets under investigation.	WP Analysis is compelling in distinguishing the presence and seriousness of splits inner part of the solid structures.
Cortez ET AL[37]	Wireless Sensor Network (WSN)	Sensor hub is a compact and autonomous used in SHM, with components microcontroller, transceiver ZigBee and digital synthesizer. The determination of damage is done by comparing the changes in root mean square voltage obtained from PZT transducer.	They are used to connect multiple patches of PZT monitor nodes and collection information of damage from different locations.
Madhav, et al. [38]	Digital Image Correlation (DIC)	Monitoring is done by utilizing PZT transducer based EMI and Digital Image connection (DIC) framework which utilizes smaller changes occurring on the surface of structure. The fatigue load makes more it serious due to fractures that are pre-existing in the structure.	In the predication of damage at early stages of on surface of the host structure or specimens considered for investigation. EMI along with image processing technology like DIC technique are used
Ellenberg et al[39] and Na and Beck[40]	Drone Technology	Visual based SHM using drone. EMI technique with drone using re detachable PZT	Drone –EMI technique showed potential in findings with the reduced thickness of steel structures.



ANN Model



Concrete Strength

Fig.4 .1-D electro-mechanical Impedance system

With the movement problem search area, each particle changes its velocity to find a better solution The flying velocity of ith particle is denoted as Vi = (vi1, vi2, . . . ,viD) (i = 1, 2, . . .,n). The Particles modifies their velocities and positions by the following equations

$$y^{*} = \sum_{l=1}^{4} y^{-1}\,\mu_l(x)\ \ / \sum_{l=1}^{4}\mu_l(x) \qquad (8)$$

Modified Particle (PSO) algorithm(MPSO), which is an improved PSO method, is used in by[34].

C. WSN

Sensors for health monitoring are more advanced with introduction newly available sensors and sensor technology, some of the sensors used for the applications are for accelerometer MEMS are used, to detect chloride ions NMR are used, detection of displacement affected by delamination shearography, to capture 3D position of objects LIDAR is utilized, to identify debonding image thermography. The new sensors subject specifically to individual type of damage like delamination or debonding, concrete cracking, steel reinforcement corrosion, cable breakage etc.

Wired sensors have restricted usage because during the construction they have to be mounted. The limitations of wired sensors can be eliminated by wireless sensors.

D. DIC Technique

DIC is an optical technique which keeps tracks of the Gray value of speckle image (black spots on white painted surface) pattern in small neighbourhoods and later utilized as pattern recognition techniques, to measure variations in the images intensity values.

Two Digital cameras with stereo capability are used for track optical targets or specify surface patterns for the located structure, since DIC uses type non-contacting measurement technique. For the entire monitoring duration images are obtained at regular smaller interval and compared with initial image (gray or black spots). For example, this method is used to monitor the positions let us say coordinates (X, Y and Z displacement) compared with initial points say (x1,y1,z1), (x2,y2,z2), (x3,y3,z3), etc. and altered points denoted as (x1,y1,z1)L,(x2,y2,z2)L, (x3,y3,z3)L , etc. obtained from monitored in the later stages of the analysis.

E. Fuzzy Logic

The benefit of fuzzy logic is analysis can be done without the requirement of mathematical model. Based on the experimental data, Fuzzy logic system here used, is trained to correlate the harmonic amplitude with the concrete strength.

To analyse Nonlinear and Uncertain systems fuzzy logic is used, the benefit of using fuzzy logic as discussed above does not require a system for analysis. The distinguishing feature of fuzzy logic is its self-learning capability. With the utilization of training data during training process learning provides expected input output mapping.

In the previous studies presented, based on data used in the investigation training to develop correlation between the harmonic amplitude and the compressive strength. In the training process of fuzzy correlation system, least square algorithm is utilized.

The fuzzy inference rule is planned in accordance with the experience such that with the increase of the strength value of concrete at early ages, the harmonic amplitude reduces at a decreasing rate.

In the Design of fuzzy correlation system, the input variable's amplitude of the harmonic response of PZT Transducer is used. In the fuzzy correlation system, the concrete compressive Strength is the output variable. To represents input and output domain with membership values in the range of 0(low) and 1(high) four linguistic variables (small, low medium, medium, large) are utilized.

In studies shows, the membership function commonly used is Gaussian membership function. To represent the different linguistic variables for input and output domains Gaussian membership function is used.

Gaussian functions are denoted by

$$\mu(x) = e^{\frac{-(x-a)^2}{a^2}} \qquad (7)$$

where x is the input variable, μ is the membership function value, σ is the width of the membership function and a is the centre of the membership function.

$$y^{*} = \sum_{l=1}^{4} y^{-1}\,\mu_l(x)\ \ / \sum_{l=1}^{4}\mu_l(x) \qquad (8)$$

F. Wavelet Packet

Wavelet packet analysis is competitive signal-processing tool. In the area of damage detection and structural health monitoring of civil infrastructures, recently there are studies done using wavelet analysis and it was found to be as effective technique for SHM of civil infrastructures because of its capability to do local analysis.

The results not only demonstrate that WP analysis is effective in identification of presence of cracks, also monitors the growth and severity of the cracks inside and within the reinforced concrete bent cap. As compared to Microscopes and LVDTs, WP analysis gives earlier indication of critical failure state of structure. Thus the WP analysis is found to be effective method in the predication of damage detection of reinforced concrete structures proposed by the author as compared with conventional methods.

Wavelet packet analysis was proposed for the analysis of seismic data. conceptually the study shaped to a present day theoretical form. Wavelet packet analysis consists of a splitting up a signal into shifted and scaled versions of the mother or original wavelet.

A wavelet is a waveform of effectively limited duration that has an average value of zero.

In WP analysis method, a signal is first divided into an approximation and a detail. The approximation is further divided into a second-level of an approximation and detail, and the process is repeatedly carried out. The advantage gained by WP is that it allows the investigation of relatively narrow frequency bands over a relatively short time window.

A damage index is used for wavelet packet analysis. From the investigation, it is evident that the WP analysis can be effectively applied in the extraction of feature vector from the signals. The WP analysis can be a beneficial signal-processing tool for health monitoring.

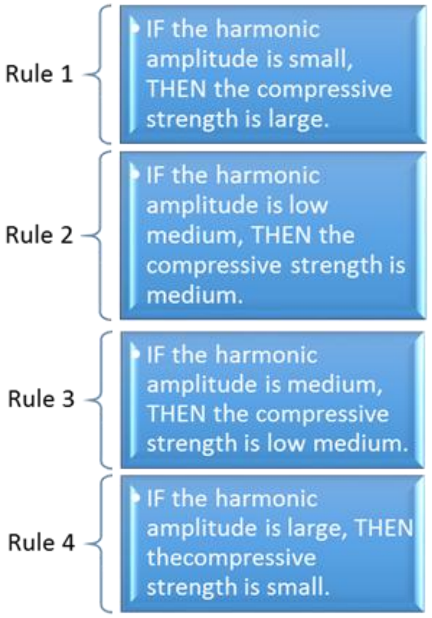


Fig 5. Fuzzy inference rules

Wavelet packets analysis is used in the effective identification and monitoring of cracks, damage detection in concrete structures. The studies presented also demonstrate the use of piezoceramic transducer along with damage index on wavelet packet analysis in the determination of cracks presence and their depth in the concrete structures. Wavelet packet analysis is used to analyze the recorded sensor signals, based on WP analysis a damage index, is made and this damage index is utilised

The failure prediction in the concrete structures was found effective and the studies have compared the results with that of conventional microscopes (MSs) and LVDTs. The results obtained by using WP analysis demonstrate their capability and effectiveness in determine presence and severity of cracks in concrete structures.

G. Drone EMI Technique

New area of research is combining EMI techniques with drone technology, with Fourth Industrial Revolution approaches, across the world, several technologies spaces are becoming significant matters that are creating interest among the researchers for their application and distinguish features in different domains.

Technologies like drones and artificial intelligence (AI) have close relation with EMI technique. The area of drones combined with EMI technique is in the early stage for the researchers, even though every day the work on ANN combined with EMI technique is extending which are or like any other non-visual based NDT methods.

Drone monitoring technology is visual inspection-based method used for monitoring along with EMI technique, although this field is advancing internal damage, small and even tiny cracks detection is some of the limitation of this technology as in visual based method, capturing and identification of internal and smaller cracks is difficult for the camera mounted on the drone.

The studies on visual based Structural Health Monitoring using drone technology are presented by Ellenberg et al. [39], on one hand, detecting internal damage of structures.is more prospective with the EMI technique, since it is a contact-based method Na and Baek [40], carried out the first work on conjoining the EMI technique with drone was executed by utilizing re-attachable PZT transducer with a magnet attached. In this work, at the hovering time of drone, the authors observed that the impedance signature did not change, irrespective of the drone vibrations. However, change in impedance signatures is due to re-attaching the PZT transducer, further work in future is essential to overcome the above discussed issue. In the proposed work, authors have concluded drone-EMI technique exhibited prospect in the detection of thickness reduction in steel structure. Irrespective of, the problem of the change in signature Sensors due to the re-attachment.

IV. CONCLUSION

A health monitoring method based on impedance measurement with advanced techniques has been surveyed and discussed in the paper, soft computing technique (ANN, Fuzzy logic, wavelet analysis, PSO), signal processing technique (DIC), Wireless sensors network, Drone technology along with impedance based EMI technique.

The investigation of impedance based health monitoring technique of civil infrastructure (concrete, RC bridges, RC beam, was surveyed. The civil infrastructures connected Internet of things is also introduced in this paper.

Further study should be directed to the investigation of shrinking age, damping. It is also recommended that performance of advanced technique to be tested on different mix proportion, varying W/C ratio and with different type of course aggregates.

A suitable material for PZT transducer or modified smart probe with suitable materials can be used to monitor and detect damages in the investigation that utilizes advanced technique along with impedance based EMI technique.

In the investigation of advanced techniques different damage index such as dynamic elasticity, poisons ration etc. can be used for in identification of damage. Further work can be carried out on improvement of dynamic bond durability, concrete, elasticity.

The application of signal processing techniques, soft computing techniques along with EMI technique, research are able to further extend with other machine learning techniques like genetic algorithm, information set, Random Forests, Decision Trees, and Nearest Neighbours etc.

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