CHAPTER 3

FINITE ELEMENT MODEL UPDATING IN STRUCTURAL DYNAMICS

3.1 INTRODUCTION

Model updating is the process of correcting the numerical values of individual parameters in a Finite element model using data obtained from an associated experimental model such that the updated model more correctly describes the dynamic properties of the subject structure. The uncertainty in the results between the Finite Element Analysis (FEA) and the Experimental Modal Analysis (EMA) is due to the assumptions made in defining unsuitable element material property and geometrical property. The effects of errors due to be short of data’s and information are analyzed using FEA and improvements must frequently be made to trim down the errors related with the FEA model. Model updating is done by correcting, improving or modifying the damping parameters, mass properties and stiffness of the Finite Element model in anticipation of a better conformity between FEA values and EMA test results is achieved. A better contest between analysis data and test results by constructing actual significant changes to the structural model parameters which correct imprecise finite element modelling assumptions is the objective of Finite element model updating .The benefit of updated FEM is that, it is capable of modelling other loads and boundary conditions without go for any additional experimental testing. The focus of model updating is constructed for analyzing the dynamics behaviours of a structure can be developed and corrected using experimental test results measured on the actual structure of a space vehicle. It becomes the most demanded and challenging applications for testing. An important requirement in
dynamic analysis is to establish an analytical model capable of reproducing the experimental results. For this purpose, EMA and FEM that describe the behaviours of the structure in terms of frequencies and mode shapes were compared. Many model updating methods have been developed, but model updating by NN has been developed in the last decades only. One unique feature of the NN is that they have to be trained to the functions. The experiment results of a Space Vehicle model and the FEA results from the software will be considered for updating. The selection of the parameters for updating is crucial because the FEM of the real structure is affected by updating the selected parameters. The important issues are the number of preferred and selected parameters from the set. Physically, the selected updating parameters must be uncertain in the model. Mathematically, if the estimation of too many parameters is attempted, then the problem can become visible and the values are difficult to find out. It is necessary to select those updating parameters that will be most effective in producing a genuine improvement in structure modelling. The quantity of updating parameters should be kept minimum and such parameters should be selected within the intend of converting predictable improbability in the model and ensuring that the data is perceptive to them. The parameters which are extensively used for model updating based on the sensitivity analysis are young’s modulus, Poisson’s ratio, shear modulus and density. All these parameters come under material properties of the Space Vehicle structure. Geometrical properties like plate thickness, structural cross sectional properties and spring stiffness were also consider for model updating.

After selecting the material and geometric properties taken as the parameters, next step is to develop an iterative NN methodology, it has been shown that the number of training samples required increases exponentially as the number of parameter to be updated increases. To minimize the number of training samples and to obtain a well trained neural model, orthogonal array method has been implemented. The random generation of training samples will
also produce best updated parameters. The investigations of selection of training samples for updating the numerical model also addressed. Numerical implementation of NN material model and geometric model are developed to learn the material response data and the structural behaviors of the model. So that, finite element model need not be analyzed to know the sensitivity of the structure.

Another important issue is the training of the sample, such that the network should reflect the dynamic uniqueness of the composition. For that the NN model would need to be re-trained during the updating process. Re-training is achieved by removing the original sample from the sample domain and by replacing it by newly predicted sample from the network.

This updating procedure is applied on Functionally Graded Material (FGM) also. The work is motivated by the recent research activity on FGMs, i.e., linear elastic isotropic materials with spatially varying properties tailored to satisfy particular engineering applications. The special case of a body with Young’s modulus depending on the radial coordinate only, and with constant Poison’s ratio, is examined in various researches. It is shown that the stress response of the inhomogeneous cylinder (or disk) is significantly different from that of the homogeneous body. For example, the maximum hoop stress does not, in general, occur on the inner surface in contrast with the situation for the homogeneous material. The results are illustrated using a specific radially inhomogeneous material model for which explicit exact solutions are obtained. The main objective of the FEA-based design of heterogeneous objects is to simultaneously optimize both geometric shapes and material distributions over the design domain (e.g., Homogenization Design Method). However, the accuracy of the FEA-based design wholly depends on the quality of the finite element models generated. Therefore, there exists an increasing need for developing a new mesh generation algorithm adaptive to both geometric
complexity and material distributions. Here we used adaptive mesh generation algorithm is proposed based on the discretization by which continuous material variation inside an object is converted into step-wise variation. The proposed algorithm first creates nodes on the iso-material contours of the discretized solid models. Triangular meshes are then generated inside each iso-material region formed by iso-material contours.

3.2 THE PHILOSOPHY OF FINITE ELEMENT MODEL UPDATING

In late 1960s there had been attempts to use the results of dynamic testing to identify the parameters in the equations of motion. There arose a problem that the number of Degrees Of Freedom (DOF) of the system (the order of the identified system) is usually larger than the number of available modes from practical testing. In such a situation, there are infinite analytical models that will duplicate the measured response with experimental errors. One may reduce the number of DOFs of the system to the number of measured modes to force a unique solution, but such a procedure will evidently reduce the reliability of the analytical model. The ability to duplicate test data does not make the model useful in itself, while a useful model should be able to predict the results of untested loading conditions and the effects of changes in the mass, stiffness, or supports of the structure. Therefore, instead of reducing the system order, the parameters (masses) used in the model should be as near to the “true” vales as possible, while the best information available as to what the “true” values are, is the approximation arrived at by the analyst. This proposal turned system identification to a priori model fitting for dynamic structure analysis. This proposal has been serving as part of the philosophy of finite element model updating. Therefore, it should be thought as the origin of the art of finite element dynamic model updating. The other half part of the philosophy of finite element model updating is that the dynamic test results are more precise than those from
analytical models’ prediction. This is evident because on the contrary, Finite Element model updating makes no sense.

3.3 UNIQUE ASPECTS OF FINITE ELEMENT MODEL UPDATING

A linear continuous structure no unique model can be yielded via using finite element model updating technique, because the mesh is arbitrarily defined by analysts and even for the same mesh the element shape function can be different which leads to different models. In fact for a continuous structure, no matter how fine the mesh has been made, an even finer mesh is always available. Therefore, topics related to the uniqueness of finite element modeling are nearly senseless and the uniqueness aspects of finite element model updating should be discussed under such a context that an initial finite element model has been reasonably established, that is, the DOFs and the connectivity of the model are unchangeable during model tuning. The most promising method selects a solution which minimizes changes in a reasonably good analytical model that includes constraints to force physical reality of the solution.

3.4 COMPARING TEST RESULTS AND ANALYTICAL MODELS

To judge the differences between experimental results and analytical predictions, the model updating techniques always require a match between experimental and analytical models. In practical cases, however, experimental model has much fewer degrees of freedom because of the testing costs and the accessibility. To match an experimental model with its analytical counterpart, one can either reduce the size of the FE model or expand the measured data to the same size as the FE model. Logically, it is possible to match them via an intermediate model. Reduction and expansion is originally a pair of terms used in dynamic finite element analysis. For the solution of dynamic finite element
analyses, reduction techniques reduce the cost of the analysis. Reduction affects
the accuracy of the finite element results. For most of the cases, reduction and
expansion are reciprocally inverse procedures as they share the same
transformation matrix. The most commonly used technique for this purpose is a
static reduction or condensation.

3.5 CORRELATION BETWEEN MEASURED DATA AND
ANALYTICAL PREDICTIONS

Model match techniques, expansion/reduction techniques, solve the
spatial inconsistence between experimental and analytical models. To evaluate
the degree of agreement between experimental and FE models, for example,
when using eigen values, it is necessary to pair modes. In the frequency domain,
two close resonance frequencies, one from measurement and the other from
prediction of a finite element model, do not necessarily mean that the two
corresponding modes are also close, because finite element models are not error
free. It is the mode shapes that are more reliable for judging the degree of
agreement between analytical and test modes. When the DOFs are matched with
expansion/reduction techniques for test and analytical models, the similarity of
the mode shapes can be expressed.

3.6 MODEL TUNING USING PROPERTY UPDATING METHOD

FEMUP techniques using property updating method can be sorted
into two categories, global methods and local methods. Global methods directly
update individual components of mass and stiffness matrices. The updated
matrix models usually reproduce the measured data exactly. However, the
updated matrix models are generally difficult to be interpreted with physical
significance. Because of this, global methods are now generally thought as
obsolete. Local methods update either the coefficients of macro elements or
physical parameters or both of them. The updated models thus evidently have
direct physical significance. According to the way of composing updating equations, the modal updating approach minimizes the errors of the modal properties while impedance updating minimizes the response errors.

### 3.7 GLOBAL METHODS

Global methods are single step approaches that directly update matrix components. They are free from iterative divergence and are usually computationally efficient. An important feature of these methods is that they reproduce the testing data exactly, which means that the measurement noise directly induces analytical model corrections and hence very high quality measurements become a basic requirement. The mostly well developed global methods are Lagrange Multiplier methods. These methods minimize weighted differences between initial and updated model matrices with constraints such as symmetry conditions and/or orthogonality conditions. These methods are more often mentioned in model error localization.

### 3.8 LOCAL METHODS

Local methods are generally iterative and sensitivity-based methods which minimize the norm of a residual vector expressing the difference between the test and analytical data. As the residual vectors can be extensively varied, local methods should be referred to as a methodology in a broad sense. The residual vectors are composed basically related to the difference between analytical and test resonance frequencies, the difference between analytical and test mode shapes and the off-diagonal elements of mixed orthogonality matrices.

### 3.9 ERROR LOCALIZATION AND PARAMETER SUBSET SELECTION

Error localization methods aim to indicate main inaccuracies in the finite element model according to experimental data. Logically every global
updating method can be developed to localize main model error areas, because in global methods no special part is assumed to be error free, which leaves opportunity of revealing errors hidden in the finite element models. Based on these global methods, various residues can also be developed to form error indicating functions. Error localization methods can be classified into two categories, Force Balance Method (FBM) and Error Matrix Method (EMM) these are the most often used location-oriented error localization methods. FBM calculates a residual force vector for each measured mode. The DOF that are not in balance indicate errors in the finite element model. It is a powerful and accurate error localization method because this method does not take any assumption in the calculation. However, as any other method, the need for reduction of the system matrices or expansion of test mode shapes due to the mesh incompatibility problem troubles the accurate localization for practical applications. As FBM is the most direct method, the errors in measured mode shapes are also directly interpreted as model errors. EMM localization process is the same as the global EMM updating process, however, with the result error matrices, error indicator vectors are developed to indicate inaccuracies associated with particular DOFs. The incompleteness of the test modes and the mesh incompatibility has greatly troubled the usage of this method. It is not ensured that the analyst-picked parameters have covered the main inaccuracies. Hence, the first step is to check whether the correcting space defined by the sensitivity matrix of chosen parameters spans the residual vector. Suppose the check has been past, the error localization is then identical to select, from the full parameter set, a subset that may most satisfactorily correct the initial FEM.

3.10 SUMMARY

In this chapter the sensitivity analysis of a Space Vehicle influences the mass and stiffness changes to the FEM model that leads to change in the model frequencies were found using property updating method. The results of
the previous analysis can be used to iteratively modify the selected FE model parameters (stiffness and/or mass related parameters) in order to improve the connection between the tested natural frequencies and the FEA resultant frequencies using NN. A model updating methodology based on a neural network model is proposed based on property updating method.