Artificial Intelligence In Mechanical Engineering: A Case Study on Vibration Analysis of Cracked Cantilever Beam

Ismail Akbani
Faculty of Mechanical Engineering, Symbiosis International University, Pune

Ashwin Baghele
Faculty of Mechanical Engineering, Symbiosis International University, Pune

Saurabh Arya
S.B Jain College of Engineering Nagpur

ABSTRACT
The advent and exponential developments in the field of computers and consequently in the area of Artificial Intelligence has revolutionized an engineer's approach towards solving complex engineering problems. Engineers, irrespective of their branch or field are starting to rely more and more on AI techniques.
One such popular technique is ANN which mimics our biological neural system to solve highly complex problems. This paper describes ANN as a viable technique for solving various problems in Mechanical Engineering. The authors also discuss a case study wherein they have applied ANN for determining natural frequencies of a cantilever beam with a crack. The case study points out that ANN technique have the potential to reduce our efforts and time, when applied to complex engineering problems.

1. INTRODUCTION
Many a times, we come across some system/ process/ phenomenon where in it is difficult to establish the relationship between the dependent and independent variables. Engineering world has several such examples where in we can obtain the output values for predetermined values of input parameters, experimentally. But it is quite difficult to map the behavior and interdependence of process/ system parameters into a mathematical model. Again solution of such mathematical models is not always an easy task. It is quite time consuming and requires high level of technical expertise. In the search of some technique that would help to create a Black – Box approach for such problems, ANN is gaining attention of the technical world. ANN basically is a computational technique that has the ability to model relationships between the process variables, given sufficient number of values for the input and the corresponding output values. In the subsequent sections, we describe ANN in brief and also discuss its applications to mechanical engineering.

2. ARTIFICIAL NEURAL NETWORK (ANN)
An artificial neural network (ANN), usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. These models mimic the real life behavior of neurons and the electrical messages they produce between input (such as from the eyes or nerve endings in the hand), processing by the brain and the final output from the brain (such as reacting to light or from sensing touch or heat).

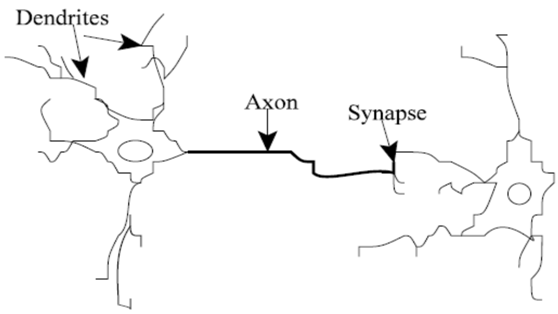

Figure-1: Biological Neural Network

A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network during the learning phase. They are usually used to model complex relationships between inputs and outputs or to find patterns in data.

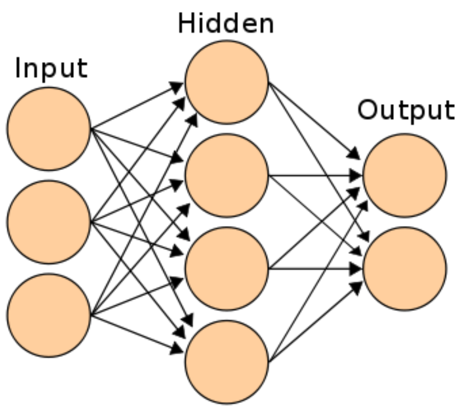

Fig-2: Artificial Neural Network

3. MATHEMATICAL MODEL OF ANN
- Inputs –These act like synapses
- Weights- They determine strength of the respective signals.
- Computational Unit –This is responsible for processesing all input signals to obtain output (it may be just summation or another network within the node).
- Activation function –It controls the amplitude of the output of the neuron (An acceptable range of output is usually between 0 and 1, or -1 and 1.)

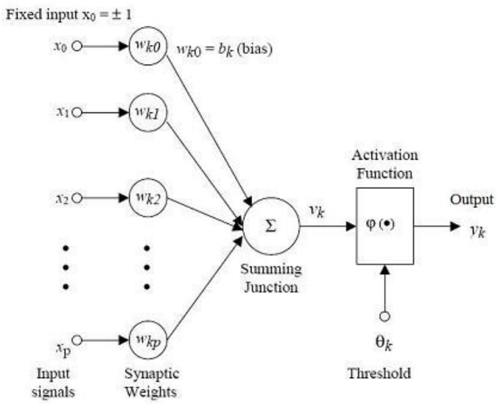

Figure-3: Mathematical Model of ANN

From this model the internal activity of the neuron can be shown to be:

$$v_k = \sum_{j=1}^{p} w_{kj} x_j$$

4. Activation function Φ

It is basically a Squashing (censorship) function. Activation function keeps the output of a neuron between certain values (usually 0 and 1, or -1 and 1) There are three types of activation functions:

- Threshold Function –It takes on a value of 0 if the summed input is less than a certain threshold value (v), and the value 1 if the summed input is greater than or equal to the threshold value

$$\varphi(v) = \begin{cases} 1 & \text{if } v \geq 0 \\ 0 & \text{if } v < 0 \end{cases}$$

- Piecewise-Linear function –It can take on the values of 0 or 1, but can also take on values between that depending on the amplification factor in a certain region of linear operation.

$$\varphi(v) = \begin{cases} 1 & v \geq \frac{1}{2} \\ v & -\frac{1}{2} > v > \frac{1}{2} \\ 0 & v \leq -\frac{1}{2} \end{cases}$$

- Sigmoid function- Its value can range between 0 and 1, but it is also sometimes useful to use the -1 to 1 range.(eg.-hyperbolic tangent function.)

$$\varphi(v) = \tanh\left(\frac{v}{2}\right) = \frac{1-\exp(-v)}{1+\exp(-v)}$$

5. TOPOLOGIES OF NEURAL NETWORKS

It relates to Distinction based on the pattern of connections between the units and the propagation of data. Following are the commonly used topologies (though there are many others too) of ANN.

a) Feed-forward neural networks: The feed-forward neural network was the first and arguably the most simple type of artificial neural network devised. In this network the information moves in only one direction — forward. From the input nodes data goes through the hidden nodes (if any) and to the output nodes. There are no cycles or loops in the network.

b) Recurrent neural networks: Contrary to feed-forward networks recurrent neural networks (RNNs) are models with bi-directional data flow. While a feed-forward network propagates data linearly from input to output, RNNs also propagate data from later processing stages to earlier stages. RNNs can be used as general sequence processors.

6. TRAINING OF ARTIFICIAL NEURAL NETWORKS

The method of setting the value of the weights enables the process of learning or training. The process of modifying the weights in the connections between network layers with the objective of achieving the expected output is called training of the network. The internal process that takes place when a network is trained is called learning. The most basic method of training a neural network is trial and error. If the network isn't behaving the way it should, change the weights of a random link by a random amount. If the accuracy of the network declines, undo the change and make a different one. It takes time, but the trial and error method does produce results. The task is to mirror the status of the input row onto the output row.

6.1 Training algorithms

Some of the popular training algorithms are-

- Back propagation Algorithm
- The simple neuron - the Single Layer Perceptron
- The Multilayer Perceptron

Of the above Algorithms the Back-Propagation Algorithm is widely used. The back-propagation algorithm uses supervised learning. We provide the algorithm with examples of the inputs and outputs we want the network to compute, and then the error (difference between actual and expected results) is calculated. The idea is to reduce this error, until the ANN learns the training data. The training begins with random weights, and the goal is to adjust them so that the error will be minimal. As the error depends on the weights, we need to adjust the weights in order to minimize the error.

7. WHY ARTIFICIAL NEURAL NETWORKS?

- A neural network can perform tasks that a linear program cannot.
- When an element of the neural network fails, it can continue without any problem by their parallel nature.
- A neural network learns and does not need to be reprogrammed.
- It can be implemented in any application.
- It can be implemented without any problem.

8. ANN APPLICATIONS

Neural Networks are successfully being used in many areas often in connection with the use of other AI techniques. ANN is used in many fields such as financial analysis, industrial management, operational analysis, data mining, scientific problems, energy sector, etc. Some of the applications are mentioned below-

- Quality Control
- Process Control
- Job Shop Scheduling
- Prediction Change and Deviation Detection
- Pattern Recognition
- Physical System Modeling

- Signal Processing
- Electrical Load Forecasting
- Energy Demand Forecasting
- Power Control System

9. ARTIFICIAL NEURAL NETWORKS IN MECHANICAL ENGINEERING

It follows from earlier discussion that for a problem where we have sufficient number of values sets for input and output variables, we can develop a Neural Network, which can be then used to predict the unknown output values for the some other input set. These features of ANN can be utilized to the benefit of mechanical engineers in the application areas such as Quality Control, Production Planning, Job Shop Scheduling, Supply/Demand Forecasting, Mechanism design and analysis, design optimization and several other areas. In the following section, we discuss a case problem, wherein ANN has been implemented for determining natural frequencies of a cracked cantilever beam.

10. CASE STUDY-VIBRATION ANALYSIS OF CRACKED CANTILEVER BEAM

Vibration analysis is one of the important aspects of mechanical engineering design. In this section, we discuss our work on application of ANN to vibration analysis of a Cantilever beam with a crack. For an uncracked Cantilever beam, we can determine its natural frequencies analytical based on basic vibrations theory and deflections formula from Strength of Material. But when the beam is considered to be having a crack, analytical methods, though possible for some simple cases, are very complex, and tedious, requiring technical knowledge from areas of Mechanical Vibrations Strength of Material, Fracture Mechanics. An alternative to the analytical method is the Finite Element Method, which is successfully applied to the problem by various researchers [6].

The FE approach again calls for several simulations of the same problem with varied crack depths and locations along the beam length, making it a time consuming affair.

We have tried to reduce the efforts using ANN. The authors selected this particular problem as the data required for training of ANN was available from one of the author's previous work [6] where ANSYS was used for FEA of cracked beam.

The cantilever beam analyzed is 300mm x 20mm x 20mm with material properties-E=206.8GPa, poisson's Ratio=0.3, density =7853kg/m^3. This beam has been analyzed by Ismail [6] using ANSYS, to determine its natural frequencies for different values of the crack parameters 'a' and 'h'.

Where,

a - Crack depth (mm).
h - Distance of crack from fixed end of the beam (mm)

Input and results from [6] have been used as training data for our ANN. Some values were excluded from training, to be used as test data. The network was programmed in MATLAB is a feed forward network. The Back-Propagation Algorithm was used to train the network.

11. RESULTS

After training the network was provided with test values of crack parameters (a and h) and first three natural frequencies were obtained. Tables (1-6) below show that the values of natural frequencies obtained by the developed ANN are in good agreement with those obtained using ANSYS.

Case-1	x/L=0.2 , a/h=0.2		
Frequency	ANN	ANSYS	Variation (%)
1	179.7553	180	-0.13613
2	1154.227	1133.2	1.821723
3	3210.578	3061.5	4.643325

Table-1

Case-2	x/L= .4, a/h=0.5		
Frequency	ANN	ANSYS	Variation (%)
1	171.9352	170.03	1.108116
2	1049.393	1016.5	3.13444
3	3050.355	2939.3	3.640709

Table-2

Case-3	x/L= .5, a/h=0.5		
Frequency	ANN	ANSYS	Variation (%)
1	177.2283	176.45	0.43916
2	1003.519	965.23	3.815488
3	3207.131	3108.36	3.079716

Table-3

Case-4	x/L= 0.2, a/h=0.5		
Frequency	ANN	ANSYS	Variation (%)
1	157.8003	154.61	2.021703
2	1147.562	1131	1.443218
3	3088.909	2981.1	3.490206

Table-4

Case-5	x/L=0.8 , a/h=0.4		
Frequency	ANN	ANSYS	Variation (%)
1	184.0744	184.64	-0.30727
2	1132.354	1114.9	1.541418
3	3004.286	2892.95	3.705916

Table-5

Case-6	x/L= .9, a/h=0.3		
Frequency	ANN	ANSYS	Variation (%)
1	184.2245	183.04	0.642986
2	1153.422	1109.7	3.790646
3	3212.007	2994.7	6.765473

Table-6

12. CONCLUSION

From the preceding discussion and case study, it can be seen that ANN can help save time and efforts for complex problems, where analytical techniques are very difficult and tedious to apply. Application of ANN in the case problem eliminates the need to remodel the beam over and again for different crack parameters and re-run the FE Analysis .Rather we can simulate the beam a few times to get enough data for Neural Network training and then rest of the desired output values can be obtained from the Neural Network itself

13. ACKNOWLEDGEMENTS

The authors wish to acknowledge the guidance and motivation of Dr. Animesh Chatterjee, Professor Mechanical Engg. , VNIT Nagpur. Thanks are also due to the Director, SIT Pune for support and cooperation.

14. REFERENCES

[1] S. N. Sivanandam, "Introduction To Neural Networks Using Matlab", Tata McGraw Hill (2006)

[2] Dr. R. K. Bansal, "Engineering Mechanics And Strength Of Materials", Dhanpat Rai Publications, (2004)

[3] Kishan Mehrotra, "Elements of Artificial Neural Network" MIT Press (1996).

[4] Dr. V. P. Singh, "Mechanical Vibration", Dhanpat Rai Publications (2000)

[5] Rao S.S., Mechanical Vibrations, Pearson Education Inc, (2004)

[6] Ismail Akbani, "Crack Detection in Beams Using Vibration Analysis,M.Tech. Thesis, Visvesvaraya National Institute of Technology, Nagpur, India (2010)

[7] P.G.KIRMSHER 1944 Proceedings of the American Society of testing and materials 44,897-904 The effect of discontinuities on the natural frequencies of beam.

[8] G.L.QIAN,S.N.GU and J.S.JIANG 1990, Journal of sound and vibration 138, 233-243, The dynamic behavior and crack detection of beam with a crack

[9] Klaus Jurgan Bathe and Edward L.Wilson. Numerical methods in finite elements analysis: Prentice Hall