Review article

Application of artificial neural network in fixed offshore structures

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Artificial Neural networks (ANNs) are good for prediction, damage detection, online monitoring and controlling in fixed jacket platform in such cases where formal analysis is tough or impossible. This paper presents state-of-the-art information reported so far on the research studies of ANN applications and future opportunity for fixed jacket offshore platforms. It is found that ANNs provide fairly accurate results as compared to conventional method. Based on the review, the future scope of work is outlined.

[Keywords: Artificial Neural network, Fixed jacket platform, Shallow water, Damage detection, Online monitoring, Prediction, Controlling]

Introduction
Several types of offshore structures are in use for oil and gas exploration due to global energy demand. Fixed types (jacket and gravity) offshore structures are economically viable for shallow water regions. Period of their service life depends on various environmental forces. Numerous studies have been carried out by conventional methods for analysis of offshore platforms. Artificial Neural Networks can calculate response in rapid mode. Neural networks are compatible to solve problems associated with fixed jacket platform. ANNs are currently being successfully used for a wide-range of problems in various fields such as business, industry and science. It helps in pattern recognition, pattern classification, time series prediction, process control, and process modeling. Neural networks are incorporated in offshore engineering and stability analysis of the rubble mound breakwater, identifying the crack extent and location of damage on the longitudinal faceplate of ship’s structure. Miri et al. presented two different types of ANN, which predicts the risk of different pipe sticking in the Iranian offshore oil field. Makarynskyy has discussed improvement of wave predictions with neural network. Mahfouz presented a successful method of predicting the capability-polar-plots for dynamic positioning systems of offshore platforms.

Many researchers have used ANN to address various types of problems in fixed platforms. Problems such as structural damage detection, damage localization, fatigue, response control, vibration control, prediction of force and moment has been presented.

The main objective of this study is to deal with a detail review on solution progression of fixed jacket platforms by implementing ANN. It has a huge potential in future, and is expected to greatly enhance the efficiency of overall production and operations activities.

Artificial Neuron Model
Artificial neural networks (ANNs) are an information-processing system encouraged by biological nervous systems, such as human brain. ANNs are able to learn from experience like people. An ANN is a combination of artificial neurons namely processing elements, nodes or units. Each processing element is fully interconnected to other processing elements by its connection weights. Processing element accepts its weighted inputs, which are summed with adjustable unit bias. The bias unit is utilized to scale up the input to develop the convergence properties of the neural network. The result of this combined summation is passed through the transfer function to produce the output of the processing element.
The artificial neurons may have single input or multiple inputs as described below.

**Single Input Neuron**- Fig. 1 shows that a single input artificial neuron model in its simplified mathematical form which has been extracted with some modification from Shahin et al.,28.

\[ I = \theta + WX \]  

(1)

where,
- \( X \) = Input
- \( W \) = Connection weight
- \( \theta \) = Bias
- \( I \) = Produced response
- \( f(.) \) = Transfer function
- \( O \) = Output.

As fig. 1 shows the input neuron \( X \) is multiplied by connection weight \( W \) to form \( WX \). The bias \( \theta \) passed into the summing junction and produced response \( I \) which is shown in Equation 1. The produced response \( I \) move into the transfer function \( f(I) \) and give an output \( O \).

**Multiple Input Neuron**- A typical multiple input neuron with a transfer (activation) function which has been extracted with some modification from Shahin et al.,28 is shown in Fig. 2. Neurons usually have more than one input which is multiplied with, each input having its own weight. The adjustable unit bias passed into the summing junction and produced response which is shown in Equation 2. The produced response transfers through the activation function and gives output.

\[ I_j = \theta_j + \sum_{i=1}^{n} W_{ji}X_i \]  

(2)

where,
- \( X_i \) = Input from node \( i, i = 0, \ldots, n \)
- \( W_{ij} \) = Connection weight between nodes \( j \) and \( i \)
- \( \theta_j \) = Bias for node \( j \)
- \( I \) = Produced response
- \( f(.) \) = Transfer function
- \( O_j \) = Output.

**Transfer (Activation) Function:**

Activation function is contained in hidden layer in between inputs and outputs. This function is also called as transfer function. Finally, an activation function controls the amplitude of the output. Each transfer function has its own formula which is shown in Table 1.
Classification of ANNs:

ANNs can broadly be divided into the following three categories, based on the arrangement of neurons and the connection patterns of the layers: Feed-forward neural networks, Feed-back neural networks, and Self-Organizing Maps.

Feed-forward neural network

A feed-forward neural network is a standard type of neural network that might be used for applications such as prediction, control and monitoring. Feed-forward neural networks are one-way connections (weights) from input to output layers through the hidden layer. Feed-forward networks often have one or more hidden layers followed by an output layer. This network propagates in forward direction, it never goes in backward direction. In a feed-forward neural network, the input numbers are served to input nodes, after multiplying by a weight it goes to the hidden layer nodes. A hidden layer node receives the weighted input from each input node, and it connects with bias. Then the result passes through the nonlinear transfer function. The output nodes come from the hidden layer node. The network is trained by trial and error, the target output at each output node is compared with the network output and the difference (error) is minimized by adjusting the weights and biases though training algorithms. The obtained optimum network can be used for various applications within the range of trained data.

Different types of transfer (activation) function

<table>
<thead>
<tr>
<th>Function</th>
<th>Mathematical Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Threshold (hard-limit)</strong></td>
<td></td>
</tr>
<tr>
<td>Binary</td>
<td>( f(I) = \begin{cases} 1 &amp; \text{if } i \geq 0 \ 0 &amp; \text{if } i &lt; 0 \end{cases} )</td>
</tr>
<tr>
<td>Bipolar</td>
<td>( f(I) = \begin{cases} 1 &amp; \text{if } i \geq 0 \ -1 &amp; \text{if } i &lt; 0 \end{cases} )</td>
</tr>
<tr>
<td><strong>Sigmoid</strong></td>
<td></td>
</tr>
<tr>
<td>( f(I) = \frac{1}{1 + e^{-\alpha}} ), ( \alpha &gt; 0 )</td>
<td></td>
</tr>
<tr>
<td><strong>Hyperbolic Tangent</strong></td>
<td></td>
</tr>
<tr>
<td>( f(I) = \tanh(vi) = \frac{1 - e^{-vi}}{1 + e^{-vi}} ), ( v &gt; 0 )</td>
<td></td>
</tr>
<tr>
<td><strong>Gaussian</strong></td>
<td></td>
</tr>
<tr>
<td>( f(I) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(I-\mu)^2}{2\sigma^2}} )</td>
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</tr>
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</table>

Here \( \alpha \) is the shape parameter so called spread parameter; the \( v \) is also used for same representation.

Multilayer Perceptron-Multilayer perceptron (MLP) is a feed-forward artificial neural network model that transforms sets of input signals into sets of output signals through hidden layer. The hidden layer and nodes play especially significant part for many successful applications of neural networks. In MLP, the input signal on a layer-by-layer basis propagates in forward direction through the network. The network is trained in supervised learning method with error back propagation algorithm.

Feed-back neural network

A feed-back network is a network with connections from the output of a layer to its input. The feed-back connection can be direct or can pass through several layers. In feed-back networks, the output information defines the initial activity state of a feed-back system, and after the state transitions to the asymptote, final state is identified as the outcome of the computation. The networks known as recurrent networks are feed-back networks.

Self-organising maps

The self-organising map describes a mapping from a high dimensional input space to a low dimensional map space and is trained using unsupervised learning. Self-organising maps are different from other artificial neural networks in the sense that they use a neighborhood function to preserve the topological properties of the input space. An ANN can also be self-organising which means that it can create its own organisation or
representation of the information it receives during learning time without any intervention from the outside world.

**Learning Algorithm:**

The neural network is trained to adjust the values of the connections (weights) to execute a particular function between an exact input response and a precise target output. This process is known as learning. There are three basic types of learning methods in neural network such as supervised, unsupervised and reinforced learning which is shown in Fig. 3. Among them supervised and unsupervised learning algorithm are most popular.

In supervised learning, the target response of the network is compared to a desired output response. If the real target response differs from the desired output response, the network generates an error. This error is utilized for adjusting the connection weights between the target and output response, till it matches with actual outputs.

Unsupervised learning does not require desired target response. The connection weights are adjusted with network according to the input values. In reinforced learning, the target response of the network is not compared to a desired output response. But only indicates that the computed output is correct or incorrect. The information provided helps the network in its learning process.

**Back-propagation Algorithm:**

Back-propagation algorithm is most popular for training the neural networks. It requires lower memory than other algorithms and commonly makes acceptable error level. This algorithm could be used in various types of networks even though it is usually suitable for training MLPs. It was developed by simplifying the Widrow-Hoff learning rule for multiple-layer networks and nonlinear differentiate transfer functions. Input and the corresponding target are used to train the network until it gives fairly accurate function. The results and calculated errors are passed forward from input nodes to output nodes.

**Performance Functions:**

The performance function is used to compute network performance in training. This is useful for many algorithms, such as back-propagation, which operate by adjusting network weights and biases to improve performance. The following functions are conventional performance functions:

- MAE = mean absolute error
- MSE = mean of squared errors
- SSE = sum of squared errors
ANN for Offshore Structures

Artificial Neural Networks (ANNs) are widely used across all disciplines of coastal, ocean, marine and offshore engineering. Mahfouz presented a method for predicting the capability-polar-plots of dynamic positioning systems of offshore platforms, stability analysis of the rubble mound breakwater, estimating the cost, uncertainties and risk analysis of floating structures, and identifying the crack extent and location of damage on the longitudinal face of a platform’s structure. ANN are also used to predict the risk of different pipe sticking in the Iranian offshore oil field. Table 2 shows the summary of research in fixed offshore platform which was carried out by various researchers during 1991-2012. Several aspects such as online monitoring, fatigue monitoring, damage localization, damage detection, response control etc. has been studied. ANNs are used for these types of problems where formal analysis is time consuming and complex. The table shows number of input variables, number of hidden layers and type of transfer function used. It helps to select the number of hidden layers and suitable type of activation functions for various aspects of fixed platform.

Fixed Offshore Structure

Fixed jackets are the most popular offshore structures for shallow-water applications. Among the various types of existing platforms all over the world, approximately 95% installed platforms are fixed jacket. Because these structures use proven technology, their machineries are easily available over the range providing reliable and cost effectiveness. The fixed platform is economical for...
installation in depth of water up to 400 m. With increase in water depth, fixed offshore structures became uneconomical and unstable.

**Damage Detection for Fixed Jacket:**

Offshore structures are prone to damage due to various types of environmental forces which exceed the design load during operation. All kinds of damage should be identified quickly so that corrective action can be taken to overcome disastrous failures. For that reason, it is expected to ensure reliable monitoring and competent system for such structures. Wu et al., developed automatic monitoring methods using neural network for detection of structural damage. Back-propagation neural network was used to recognize the behavior of the undamaged structure and also observed the behavior of the structure with different probable damage states. It was found that the developed monitoring method is able to detect any existing damage. Mangal et al., proposed adaptive resonance theory (ART) for online monitoring to detect damage and location of fixed jacket platform. BPN and ART network were used for comparison of damage detection. ART networks work as pattern recognition, has the ability to train new data or adapt themselves to new conditions. Speech recognition and object identification problem can be explained easily with BPN. It was suitable to use both BPNs and ART simultaneously for good results. Banerji and Datta used ANN for monitoring the integrity of offshore structures. Feed forward neural network algorithm was used for pattern recognition and comparing measured RMS displacement responses at different elevations of an offshore structure for various sea states. Lopes and Ebecken proposed a method using neural network for fatigue monitoring of fixed offshore structures so that an automatic fatigue data gaining on board and performing in-time fatigue calculation to the actual loading condition can be achieved. Finite element method and stochastic fatigue analysis were used for fatigue damage calculation of the 8 brace locations of each selected joints during 20-minute periods. The results clearly indicated that the fully connected network produces small errors and better performance. A laboratory jacket platform model to access the feasibility of adapting vibration responses due to impulse and relaxation for on-line structural monitoring has been investigated by Mangal et al.,. Effects of damage in six members of the platform and changes in deck masses were studied. A finite element model of the structure was used to analyze all the cases for comparison of results and system identification.

Zhen and Zhigao proposed the time-domain response data with measurement noise under random loading for detecting damage of offshore platforms. A sensitivity matrix consisting of the first differential of autoregressive coefficients of time-series models with respect to the stiffness of the structural elements was obtained based on time domain response data. Numerical simulations show that the use of few sensors acceleration history data with certain level measurement noises is capable of detecting damages efficiently, and the increase in numbers of sensors helps in improving the diagnosis success rate. The damage localization of the fixed platform has been presented utilizing probabilistic neural networks (PNN) by Diao et al. The members of offshore platforms were classified and separated into several layers and the decision system for the type and layer of damaged members was established using the back-propagation network (BPN). The experimental results show that the trained neural networks are able to detect the damages with reasonable accuracy.

Damage detection under random loads were evaluated by the combined method of random decrement signature and neural networks by Elshafey et al. The random decrement technique was used to extract the free decay of the structure from its online response while the structure was in service. The free decay and its time derivative were used as input for a neural network. The output of the neural network was used as an index for damage detection. It has been shown that function N (number of segments) was effective in damage detection in the members of an offshore structure.

**Controls for Fixed Jacket:**

The safety of offshore structures is a significant concern under the oceanic environmental loads. The reduction of the dynamic response of offshore structures subjected to random ocean waves has been a critical issue in terms of serviceability, fatigue life, and safety of the structure. A number of studies have been carried out to control vibrations in offshore structures using ANN.

Modified probabilistic neural network (MPNN)
was used for controlled response of fixed offshore structures subjected to random ocean waves. Linear quadratic regulator (LQR) algorithm was used for calculation of control forces under random ocean wave. Significant decrease in structural responses proves the MPNN control algorithm as an effective vibration control technique.

Nonlinear interactions of pile-soil by wave load disturbances of offshore jacket platforms was studied by Liang et al. Morison equation was used to estimate the wave load disturbances. Results of feed-forward and feedback vibration control jacket-type offshore platform were significantly effective. The vibration control was studied with an active mass damper and presented a feed-forward and feedback optimal control (FFOC) under irregular waves. The reductions of lateral deck motion under different control laws were compared. The simulation shows that FFOC was more efficient and robust than the classical feedback optimal control (CFOC).

Hong-yu and De-you proposed grey neural network as adaptive predictive inverse controller, which was implemented to the active control of jacket offshore platform. The simulation results show that grey neural network has strong robustness, and can effectively control the displacement of jacket offshore platform under random loads. Ya-jun et al. presented classical optimal control using artificial neural networks for structural control of offshore platforms under random waves. BPN algorithm was used for active control. Result shows that the active control was feasible and effective. Cui and Zhao proposed an approach of rough neural network as an adaptive predictive inverse controller for active control of offshore platform under the combined action of random waves and winds. The result showed that the proposed rough neural networks were fast in training speed and strong in robustness. The displacement response of platform top was effectively controlled and the time delay was sufficiently suppressed. This method also possesses strong anti-disturbance capability.

An adaptive inverse control method on the basis of novel rough neural networks (RNN) to control the harmful vibration of offshore jacket platform was proposed by Hong-yu et al. The offshore jacket platform model was established by dynamic stiffness matrix (DSM) method. The constructed novel RNN has advantages such as clear structure, fast training speed and strong error-tolerance ability. Furthermore, the proposed method based on RNN could effectively control the harmful vibration of the offshore jacket platform. A new neuro-control scheme was applied to the vibration control of a fixed offshore platform under random wave loads to examine the applicability of the Lattice Probabilistic Neural Network (LPNN). The results of LPNN showed better performance in effectively suppressing the structural responses in a shorter computational time. Wei & Gong-you investigated the optimal control for linear systems affected by external harmonic disturbance and applied to vibration control systems of offshore steel jacket platforms using ANN. It was established that the control scheme was useful in reducing the displacement response of jacket-type offshore platforms.

The control method for fixed offshore platforms using semi-active tuned liquid column damper (TLCD) was presented by Hong-nan and Lin-sheng. A back propagation artificial neural network was used to adjust the orifice opening of TLCD because of the nonlinear motion of liquid in TLCD. Ya-jun and De-you proposed a new active control scheme on the basis of neural network for the suppression of oscillation in multiple-degree-of-freedom (MDOF) offshore platforms. The obtained results show that the active control was feasible and effective, and it finally overcomes time delay owing to the robustness, fault tolerance, and generalized capability of artificial neural network.

**Response Prediction of Fixed Jacket Platform using ANN:**

Offshore structures are subjected to external environmental load such as wind loads, wind generated wave excitations, and current forces. The dynamic response prediction of offshore structures in a random environment is a significant aspect of design. ANN has been successfully used in offshore structures for prediction of dynamic characteristics by limited number of researchers.

Elshafey et al. provided a deck acceleration measurement tool to predict the value of the force and moment acting on the offshore structure foundation subjected to wind generated wave excitation. Neural networks and Fokker-Planck formulation methods were used to determine the
relationship between the force and moment acting on the foundation and deck acceleration. The total virtual mass of the equivalent single degree of freedom formulation of the structure was determined at different deck masses. Yun and Bahng used back propagation neural networks (BPNN) to estimate the number of unknown parameters of jacket platform. The jacket-type offshore structure was presented to illustrate the proposed procedure and to demonstrate the effectiveness of the method. Mandal et al. addressed the prediction of stress resultant deflection of fixed offshore platform under varying sea environments using neural networks. With the data of deck displacements at various loading states, the Back-propagation neural network was first trained and later prediction of the deck displacements is obtained for any loading state. The result showed that prediction of deck displacement was significantly accurate.

Yasseri et al. proposed a predictive method for identifying the range of sea-states considered safe for the installation of offshore structures using FEM method and ANN. A finite element dynamic analysis was performed and a table of some safe and unsafe sea states has been prepared based on the pile allowable stress. Multi-layer feed-forward neural networks were used to determine whether the predicted sea state is safe or not.

**Conclusion**

This paper gives a detail literature review on the fixed offshore structures using ANN. It includes the research on damage detection, online monitoring, control, and response prediction of shallow water structure. In addition, this study attempted to address the details of ANN configuration. ANNs have satisfactory advantages over conventional computing techniques. However, there are no structured methods today to identify the network structure which is best to approximate the function and mapping the inputs to outputs. Hence, the tedious experiments and trial-and-error procedures are often used. ANNs can deal with more data and requires less computational time for training. The design parameter prediction such as shear force, torsion and deflection for fixed jacket structural elements by ANN is still young. Furthermore, long term decay by sea water and corrosion experienced in such structures are to be explored in optimum manner. ANNs can ensure itself as competent tool for such predictions.

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