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ANN based Intelligent Mechanical Engineering Design: A Review

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Abstract

Objectives: The application of Artificial Intelligence (AI) has perceived in all fields such as in the intelligent based control, the design of the intelligent based mechanical systems, pattern recognition-based systems, knowledge processing reveals the application of AI. **Method/Statistical Analysis:** In this paper, a review on the applications of ANN in the intelligent mechanical engineering systems such as diagnosis of faults in machines, the analysis of mechanical structure, geometry modelling of the mechanical structures, mechanical design and its optimization were studied and an extensive review was done. **Findings:** The adaption of Artificial Neural Networks (ANN) is still in the earlier stage of development especially in the field of mechanical engineering. This review points out the various applications of ANN in intelligent based systems and the potential to minimize the efforts and time and to obtain more effective system for mechanical based design and fault identification. **Application/Improvements:** Future enhancements in this wok are to include more applications of AI in the design of mechanical based systems.

Keywords: Artificial Intelligence, Intelligent Fault Identification, Mechanical Design, Mechanical Engineering, Neural Networks

1. Introduction

Artificial Neural Networks (ANN) is applied recently across almost all the engineering applications such as computer-based applications, mathematics-based applications and mechanical engineering-based applications. It comes under the area of adaptive based programming system in an engineering application. Generally, ANN[1] is a new information processing methodology. Its main principle relies on the research based on modern neuroscience with the combination of many parallel, segmental and simulation-based approaches which tries to reveal the basic characteristics of processing the information based on the working of a human brain[2]. Recent researches[2-8] shows a massive development of ANN in mechanical engineering based on intelligent structure and its design, in its optimization. ANN is an advanced computational methodology which has an ability to model the relationships between the various processes and its variables when a sufficient number of values is given for the input and to its corresponding output.

The overall structure of the modern mechanical based equipment's become more complex due to the rapid growth and application of technology. It also has a very high degree of automation. ANN has a substantial claim in the mechanical engineering field nowadays[2]. Its technology is extensive in various fields of the mechanical engineering such as the design of machine, manufacturing and its operation etc. In this paper, a review on the applications of ANN in the field of mechanical engineering such as an intelligent machine faults diagnosis, the analysis of mechanical structure, mechanical design and its optimization is done from various recent researchers. This review is arranged as follows: Module 2 depicts the detailed Relationship between AI and Mechanical Engineering with its architecture. Module 3 presents the methodology of the Artificial Neural Network. Module 4 explains the types of Artificial Neural Networks used in

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the mechanical field. Module 5 depicts in detail its uses and applications of ANN in the field of mechanical engineering, such as intelligent fault diagnosis, mechanical structure analysis, mechanical design and its optimisation etc. Finally, module 6 depicts the conclusions about this survey.

2. The Relationship between AI and Mechanical Engineering

Due to the expeditious growth of technology, mechanical engineering is widely considered as a basic discipline in the routine life. Yet, the technology based on mechanical engineering has various disadvantages such as the inconsistent system because the faulty factor of the mechanical based system. The AI can rapidly exchange the input and it can also process it in a timely manner such that the output is not affected. It can also make effectively decisions for this defect. The overall process of transforming the input in to output in mechanical engineering-based technology, the ordinary information system must overcome more difficulties, when the nature of the input information is more complicated. The ordinary information system may make more mistakes than the manual information system. In order to overcome these disadvantages, AI based automated processing systems ate more necessary. If the AI is combined with mechanical engineering, then it is easy to solve the flaws of mechanical engineering.

The basic architecture of AI based system and its working principle is shown in Figure 1. Initially, the input which is given by an end user is a data which is adopted by the machine via the interface called a human-machine[9]. Secondly, a machine-based reasoning module initializes the respective rules to obtain the results based on the methodology called as positive reasoning. This methodology will contribute the advice from an expert for the findings and then it redeems the output in a database through a predefined procedure or an algorithm. This process is done eventually to get the output which is almost same. Then it computes the similarity present in it based on the previous results and computations and then it completes the process of diagnosing the mechanical faults more accurately.

3. Artificial Neural Network

An artificial neural network is a calculative model of AI that is motivated by the overall architecture or functional contents of a Neural Networks (NN). These biological models copy the idealized world character of neurons

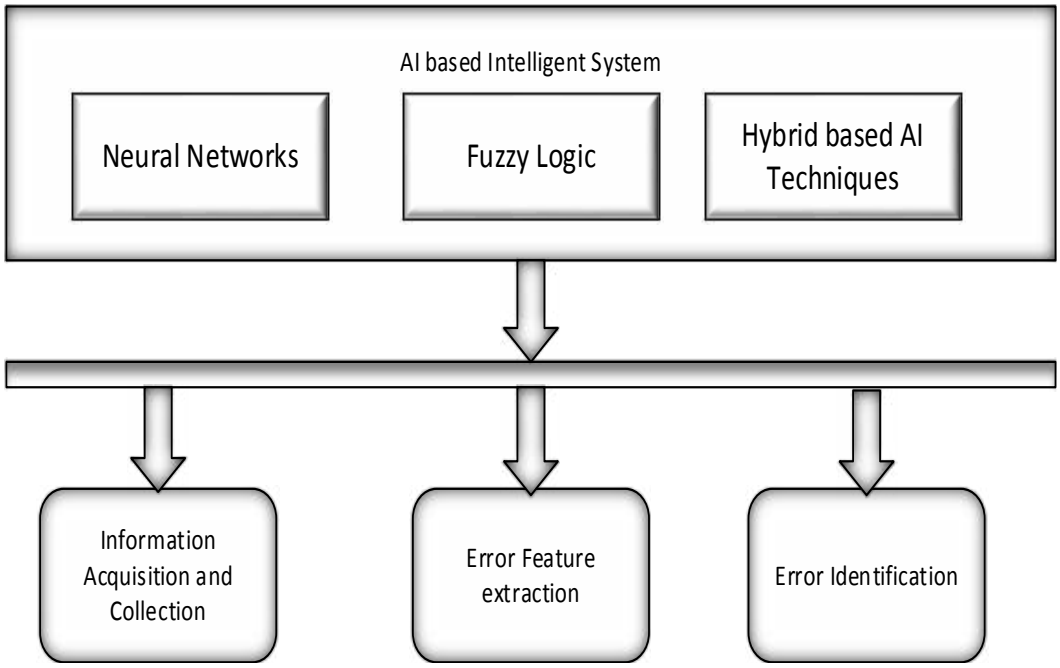

Figure 1. The overall architecture of an AI based intelligent system.

and the electrical based signals produce between them. These signals can be processed and then it is transferred as outputs. A typical NN comprises of an interlinked cluster of artificial neurons. It computes the obtained signals as input using an approach to calculation. Each neuron consists of an output function for each specific input. It is called as an excitation function. The links which connects between the two neurons represents a weighting priority through the signal connected to it. It is defined as the weight. When the mode of connection, mode of weight and its function changes in the NN, the output of network will also change[10-11].

4. Types of ANN'S Used for Mechanical Engineering

Following are the various intelligent methodologies based on ANN's which are used for designing and error removal in the field of mechanical engineering. When the time and research goes through, the other ANN based technology in mechanical engineering will be used in more applications.

4.1 Back Propagation Neural Network (BPNN)

The BPNN is multilayer based feed forward type network which works based on the BP algorithm[10]. The BPNN is currently used in various applications including the mechanical engineering field which is a multi-layer-based network which has three layers. The nonlinear function is used as a conversion function in the hidden layer. The algorithm of BPNN is classified into two steps: First step is the active dissemination and the second one is back propagation process.

4.2 Hopfield Neural Network (HNN)

It is a Network based Hopfield recurrent NN model. In this network, a feedback there is from the output to the input as a connection. Generally, the Hopfield network has two Feedback such as the discrete and continuous. This network is feedback in nature. Hence, this network will produce a constant state of output. In the input, the user can alter or remove the output of the entire network based on the Hopfield's invocation. Then, the output can be fed back to the input for producing a new output.

4.3 Self-Organizing Map (SOM) Network

It is a self-organizing type of combative NN. In this Network, there are two layers ate present such as the input layer and output layer. The output layer consists of neurons of two-dimensional array in nature. The two layers are connected to each other through the neurons. In this NN, the Training is done with the help of nodes present in the output layer.

5. Applications of ANN in Intelligent Mechanical Engineering

Neural networks have been used in the past for the application of identifying the faults in rotating machines since it has automatic learning ability. This property of the NN makes it to identify the errors by using the trained data's. Apart from this ability, the NN can be also used for solving the nonlinear type of problems which are complex in nature. These problems may be more complex for diagnosis. Various technologies based on AI are frequently used for finding the failure in mechanical engineering at present[6,12-14]. Normally, AI-based fault recognition methods include reasoning based on rule, reasoning based on case and tree fault-based identification. From the basic configuration and basic architecture of the conventional system based on expert, an expert-based fault identification mechanical system is developed. It has a manually based case database, rule-based database for fault identification, database diagnosis for various types of fault, machine knowledge-based processing for fault reasoning, interpreter for the fault identification process, a system for learning and a system for the interface between man and the machine.

5.1 ANN based Mechanical Fault Diagnosis

Intelligent based fault identification starts with the acquisition and collection of information which are related to the errors. For extracting the feature, the spectra obtained from its frequency have to be obtained. These error feature extraction methods can be classified in to two types namely statistical as well as model based[15-16]. It includes various algorithms which can process all types of signals that are obtained from these machines. The overall process is shown in Figure 1. Various NN's such as BPNN, Radial

Basis Function Neural Networks (RBFNN), (SOM) and Principal Component Analysis (PCA) are used.

Generally, the process of intelligent fault identification is done when the inputs are given towards the neurons which generates the outputs based on the signals and faults present in the machines. By using these NN's, the user who is training and testing the methodology need not used to study the complete NN. The error identification in Mechanical engineering-based technology is based on the accession in the overall working of the equipment based on the information of comparative constant condition, the examination of the constant signal and then merging it with the objects dentification condition, to measure the mechanical technology of real world Mechanical based machines, and to identify the uncommon defeat and also to speculate the upcoming position of the technology[6]. Its main policy is to use the latest adaptation of all the technology which are present in earlier researches are related to the mechanical engineering for avoiding errors. Identification of errors in the mechanical based machines which can be applied in industries, can be easily identified by the presence of some error, and repair analysis method. Identification of errors or faults in Mechanical engineering-based technology is the outcome of the growth of modern technology and it is based on the technology management procedure.

Fault identification is the key role to understand the basic symptom of the error as fault. The traditional of finding the errors is a reasoning based symbolic expert system. But, this system finds various faults such as, to find the system which cannot reach the necessary stage, the ability of an ANN is self-learning, the ability of system towards non-linear based mapping, ability of computing parallelly and tolerance of error in building an advanced error identification system. An ANN based error identification system uses an input to find the status of fault based on its symptoms by doing the numerical based computations. In general, it includes the interface between human and the machine-based modules, diagnosis and reasoning of knowledge base, information retrieval module and finally the learning module for the system. Some of the NN's which are used for the identification of errors in the rotating machines, are shown in Table 1.

Table 1. Some NN used for finding the errors in Mechanical machines

Neural Networks	Gears	Shafts	Motors	Bearings
BPNN	20	2		21
HNN		1	1	
SOM			9	
RBF		21		21
PCA	6			

5.2 ANN based Intelligent Diagnostic System for Rotating Machinery

In the scenario of fault identification in equipment based on mechanical engineering during the past years, the overall methodology of fault identification of rotating machinery has improved. The achievement attained a great economic height in the practical implementation. The proposed methodology is a universal based neural network identification system in application of fault identification in rotating machinery in fan. The identification has two major parts. First one is the fan and the second one is motor. The main unit of this system can be further divided into five sub parts such as vibration-based parameter, temperature-based parameter, noise and oil-based parameter.

5.3 ANN based Intelligent Diagnosis System for Reciprocating Machinery

One of the main factor of the motion quality reciprocating machinery is it has a set of very high in speed of reciprocating. Its dynamics-based morphology is more complicated when compared to the rotating machinery. Due to this character, the identification of fault is more difficult in nature. The previous mechanismsfor failure and along with its methods carried so far for diagnosis is not sufficient. Diesel engine is a reciprocal based machine which responds to a diagnosis system based on an integrated neural network. This machine is a universal NN based integrated identifying system which is fixed in the error or fault identification system of a diesel engine and its applications. Various types of failures in the diesel engine can be categorised into performance-based failure and mechanical-based failure. The performance of error identification in this NN based machines can be obtained more effectively using an additional NN. The performance parameters of this NN is an input which consists of power based, speed based, pressure of the cylinder, temperature of the water etc. The various faults in the mechanical based engine is identified by two additional

NN based systems and the integrated NN based identification mechanism. The complete mechanism is formed by the combination of vibro based acoustic (VA) signal and the oil analysis process.

5.4 ANN based Fault Diagnosis to Hot Film Forging Press

In the process of production of hot forging presses, various errors can be occurred such as the stopping of slider outside the location, stuffy car, the current of motor is more, failure in lubrication etc. These errors can be caused by various reasons[17]. The fault diagnosis of the production process of the hot forging press is based on the rule reasoning and the case reasoning. The system processes the error based on the library and then it records the error number in the library. The algorithm which is used to analyse the similarity of case matching is as follows:

$$res(Y,B)=\sum_{j=1}^{m}X_j res_j\left(f_j^y f_j^z\right)/\sum_{j=1}^{m}X_j \quad (1)$$

Where, X_j is the weight of the *jth* credit, f_j^y depicts the value of the *jth* credit for the fault *Y*, f_j^z represents the value of the f_j^z of the condition B, $res_j\left(f_j^y f_j^z\right)$ is the resemblance of the error *X* and the retrieval condition is $\sum_{j=1}^{m}X_j=1$. Since the credit values are different, the calculation is nit similar.

$$X_j = f_j log\left(\frac{M}{M_j+2}\right) \quad (2)$$

Equation 2 is used to calculate the similarity of the angle of weights.

5.5 ANN based Mechanical Structure Analysis and Geometric Modeling

Structure analysis in mechanical engineering can be used to realize the design parameters which can be used to modal the mapping parameter[18]. Generally, the method which is used is the finite element analysis is now replaced by ANN based methods in order to identify as well as for the process of mapping. In various structure of the data which were obtained by the finite element analysis, it is further used for training the BPNN, the average or overall value of the training parameter is further used by the structure analysis parameter of NN. The process of structure analysis and the dynamic design is used to understand the parameters of modal with the process of relationship mapping. This is the overall process of structure analysis in mechanical engineering. But the solution is too difficult to analyse the overall mechanism. A mechanism which is used in the finite element-based procedure called the structure analysis of the data or the training of BPNN. This mechanism uses the input of artificial neural network as modal parameters and the output as design parameters to identify and analyse the relationship of mapping between both of them. It can also be used for the modification of the overall structural dynamic design.

The complex surface modeling, one of the classification of geometric modeling particularly uses the spline function fitting mechanism. This mechanism is more complex with various boundary conditions. Changing its disadvantages is more difficult. It needs huge calculations and steps. The nonlinear mapping methodology of ANN used in geometric modeling is an advanced step in the mechanical engineering. The calculation is with the particle surface of coordinates as X, Y which is given as input and the coordinate Z is given as the output. These coordinates are chosen for training the sample set of ANN. This can be identified by the curved shaped surface of modeling.

5.6 ANN based Mechanical Design and Optimization

Structure of the mechanical engineering-based systems and machines are complicated nowadays. The complexity arises in these mechanical engineering-based systems due to its static properties such as the stiffness, strength, pressure, etc. and the dynamic response properties such as the force, displacement, speed, acceleration, frequency and vibration are considered as the optimization problem[2] which is integrated in nature. This integrated problem is based on mathematical calculation. The optimization problems are classified based on size, topology and performance. Various optimization methods based on mathematical based programming is insufficient to make a difference in these types of optimization problems.

The Hopfield NN has a property of maximum energy tending towards a stable state. Due to this property, the above-mentioned types of optimization errors can be changed towards an energy function solution of ANN. The dynamic system of ANN is one of the property of

the objective function is the point of minimum, from the point of initial state. The ANN can also be used in the minimum point in order to complete the calculation of optimization. The application of AI in solving the optimization problems is depicted in[4]. In their paper, the authors explained the application of AI based methods in solving various optimization of several problems[19]. This methodology is used for optimizing various problems such as 2D structures and the 3D structures, composites structures, vibrating systems, it can be also used to identify the acoustics problem. The optimization of thermoelectricity-based problem based on coupled field is performed in[20]. Coupled field is defined as the consideration of bodies which were subjected to concurrent knock of thermal and mechanical fields. Another application of the AI based systems is the optimization and identification of certain numerical values which fits for the composite systems, which is having a proportion of high strength-to-weight when compared with regularly used materials.

6. Conclusion

In this paper, an extensive review regarding the types and applications of the Artificial Intelligence, along with its correlation between the mechanical engineering for the process of mechanical fault identification and design is proposed. This paper comprises of the summary related to the exact applications of AI in the field of mechanical engineering. Various applications such as error identification, Diagnostic System, mechanical structure analysis, and mechanical design are extensively reviewed. This study reveals that the AI based intelligent methodology is widely used widely in the complete mechanical engineering field. This paper also concludes that the Mechanical engineering field can be easily coupled with various other AI based technology to make it more effective to improve in the mechanical system. Future work is to implement the AI based systems for proposing a hybrid based intelligent design of mechanical systems for the purpose of observing, controlling, the error identifications system based on AI based systems such as the Fuzzy logic and Neural Networks for improving the present state of mechanical engineering.

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