Application of principles of a Artificial Intelligence in Mechanical Engineering

S.Anush Lakshman, D.Ebenezer*
SSN College of Engineering, OMR, Kalavakkam, Tamil Nadu-603110
E-mail: ebenezerd@ssn.edu.in
anush18014@mech.ssn.edu.in

Abstract. As the world is tuning smart in every possible way, various engineering problems and processes are being made smart by the use of Artificial Intelligence (AI). As various AI methods are being tried in variety of applications in mechanical engineering like fault detection, autonomous vehicles, manufacturing, smart buildings etc., it becomes essential to survey and understand their suitability and performance to heighten the use of AI. Hence, this paper aims to survey the use of AI methods like artificial neural networks, genetic algorithm, deep learning, fuzzy logic, hybrid technique and case-based reasoning in some of the mechanical engineering applications and attempt to find out which AI method suits better for the applications discussed.

1. Introduction
Artificial intelligence is becoming popular in almost every field. We are making everything smart, from TVs, watches, wallets, rings, etc. Not only has it made our job easier but also has opened up a new dimension to research, work and improve. AI is an ocean of other sub-topics and algorithms that aid us in performing our operations in a more efficient way compared to humans. Machine Learning is an integral part of AI. It is the process by which the machine gains its intelligence. A more formal definition can be stated as, A computer program is said to learn from experience E with respect to some task T and some performance measure P, if its performance on T, as measured by P, improves with experience E. To have a better understanding of this let us consider a human example. Let us consider a student studying a particular topic, say Linked lists. This is the task T. It takes more time to learn the concept, hence performance P, is less. Now let us say he has done some five programs on linked lists and gained experience E. If he comes back to revise the basics of linked lists (T) he will take a comparatively less time; improved performance P. Machine Learning maybe divide into three major sub-categories:

1.1. Supervised Learning (SL):
The program is trained to do a given task by a given set of pre-determined operations as examples (i.e.) sample inputs and outputs. When given a new set of values, it displays the output based on the given training examples. Let us consider a simple example, if I define an addition operation to a computer with the help of certain set of training examples, then if I give two new numbers, the
program performs addition. But, this kind of program can be used only to perform addition and not multiplication or division.

1.2. Unsupervised Learning (UL):
The program is just given a set of data. The function of the program is to find links and relationships between the given set of data. Let us consider stock market data of the past one month has been given as input to the computer. Now it calculates and predicts the stock market at closing the next day or next week. More the data you supply (E) more the accuracy (P) in predicting the stock market (T) [1].

1.3. Reinforcement Learning (RL):
This method of learning involves a decision-making process in situations where a reward has to be achieved. Let us consider a maze, say where a rabbit has to cross certain obstacles to reach its babies. Here, RL algorithms are applied to make the task easier [2].

2. Artificial Neural Networks
The main objective of an AI is to mimic the functions of a human and do as many human activities as possible, more efficiently. So, we construct an AI using algorithms and machine learning so that they are mimic human intelligence as close as possible. After constructing the learning part of an AI, we construct what is known as an Artificial Neural Network (ANN). To understand this better, first let us understand how a biological (i.e.) human neural network, as shown in figure 1, works.

![Human Nerve Cell](image)

Figure 1. A human nerve cell [3].

A neuron or a nerve cell, as shown above, is a cell which receives signals from the receptors and transmits the required action to the particular body part. For example, if we touch a hot pan with our hand, the receptors transmit the feeling of hot via the nerve cells to the brain, which then sends the reaction, that is, withdrawing your hand quickly. The cell body or soma is the body of the cell. The dendrites help the neuron to receive signals or information from other nerve cells and send it to the soma. The body then transmits the action that has to be performed via the axon. So, the dendrites act as receivers, and axon acts as a transmitter. The axon at the end, branches into strands and sub-strands. At the tip of these strands are synapses. A synapse is the functional unit between two neurons (the axon of one nerve cell and the dendrite of another). When the impulse sent by the soma, reaches these terminals, certain chemicals called neurotransmitters are released. These neurotransmitters diffuse along the synaptic gap to either enhance or inhibit depending on the receiving neuron’s tendency to emit electrical impulses. The quality of the signals passed mainly depends on the electrical signals
transmitted. This is where our memory comes into picture. Now, since we’ve looked at biological nerve cells in detail, let us look at an Artifical Neural Network with the help of a model. The McCulloch-Pitts neural model, treats the neural network as a linear threshold gate. The main function of this is to classify the given inputs into two classes. Hence, as we say in computer science the output is either 0 or 1 (i.e.) binary [3].

2.1 Applications of ANNs

These ANNs are used in fault detection and autonomous vehicles. Fault detection in cracked beams [4], on-line fan blade damage detection [5] and fault detection in gas insulated substations [6] are some of the recent advancements in approach towards fault detection in various fields of mechanical engineering. In autonomous vehicles an ANN can be applied just like a human neural network. For example, let us say we are driving a car. We suddenly see a dog crossing the road. Now we’ve to apply brakes. That is the synapse to be sent via the axons and dendrites, as seen earlier, to the brain. Similarly, we can program an AI by creating a similar setup to avoid obstacles[7]. Additionally, we can also define a function to increase or decrease the speed depending on the traffic present. Neural networks may also be used in optimizing tool path during mechanical operations like welding [8] and obstacle detection [9].

3. Genetic Programming and Algorithms

The major difference between a neural network and a genetic algorithm is as follows: Neural network is a way to describe a trainable function which is known to perform very well on a wide variety of tasks, whereas, Genetic algorithm is a randomized numerical optimization method. Which means it gives the parameters which optimize a particular function. Genetic algorithm starts with several randomly chosen parameters and retains the set of parameters which minimizes loss.

Genetic programming is the process of evolving programs from unfit programs. This is similar to applying the natural genetic process to the population of programs. Like in natural genetic processes we apply methods like selection, crossover, mutation, which can be applied in genetic programming also.

3.1 Applications of Genetic Algorithms

Like ANNs, GP can also be used in fault detection [10, 11]. Both ANN and GP can be combined and used as well [12,13]. Genetic algorithms provide the base for neural networks and they can be applied in fields along with ANNs to make them more effective.

4. Deep Learning

As the name suggests, the concept mainly relies intensive Machine Learning techniques (i.e.) a combination of supervised and unsupervised learning. Deep Learning, also known as Hierarchal Learning, was mainly used in applications where pattern recognition was required. It works on the logic of Non-linear processing. This method is when the output of the present iteration is passed as the input of the successive iteration. The learning (be it supervised, unsupervised or reinforcement) architectures are mainly based on Neural networks (convolution, recurrent, deep neural networks, deep belief or Bayesian Networks). Convolution neural networks are neural networks that operate as shown in the figure 2. They are mainly used to process data in the form of arrays and pixels like in image processing. On the other hand, Recurrent Neural networks are used in applications that require sequential input, as in, speech and language processing [14-16].
4.1. Applications of Deep Learning

Deep learning has a wide range of applications in the field of mechanical engineering like fault detection in tires [18], predicting mechanical properties [19], green manufacturing [20], image processing in vehicles [21]. Deep Learning occurs in specified steps and they can be applied majorly in places that require image processing as in night detection.

5. Soft Computing and Fuzzy Set theory

This is a subset of the ocean of Soft computing. Soft computing is defined as the use of various algorithms and methods in order to get solutions for real world problems, which becomes tedious when mathematically worked out. The main objective of this method is to mimic the action of human brain and make decisions with more accuracy and precision. Soft computing mainly comprises of fuzzy sets, Neural Networks and Genetic Algorithms. The logic behind neural networks and genetic algorithms are already discussed above. Fuzzy logic involves three major steps:

5.1. Learning:
This step involves providing knowledge to the computer in order to perform the decision-making process.

5.2. Decision-making:
This is the main process in fuzzy logic where decisions are made based on conditional statements called as fuzzy statements.

5.3. Defuzzification:
This is the process of producing the output by the superposition of various rules.

Apart from fuzzy logic other soft computing methods like Probabilistic Reasoning or Bayesian networks, Ant Colony Algorithms and Evolutionary Computation [22, 23] are also in use.

5.4. Applications of Soft Computing

Methods like Fuzzy logic, Rough set theory, Evolutionary Computation are used in fault detection in various machines. Faults in bearings and reluctance motors are detected using fuzzy logic [24, 25],

Figure 2. A brief operation of an ANN [17].
Rough set theory can be used in various data recovery/image recovery processes [26, 27]. Soft Computing mainly finds its application in data recovery and places where decision-making process is involved.

6. Hybrid Techniques

As the name suggests, hybrid techniques involve the use of two of the above mentioned techniques among neural, fuzzy, genetic algorithms. They are mainly applied in order to improve the working of the algorithm. Figure 3 shows the various combinations of the intelligence methods used in the industry today and their popularity

![Figure 3](image)

**Figure 3.** Combinations of the intelligence methods used and their popularity [28].

6.1. Applications of Hybrid Techniques

Neuro-fuzzy techniques are used in applications like vibration-monitoring [29] and crack-detection [30]. The process of vibration-monitoring is mainly based on a standard fuzzy system, whose fuzzy rules are reduced with the help of neural networks. The quality of evaluation of the system is measured by using two famous data sets, namely, Fisher’s Iris data set and Westland’s vibration data set. A device called an accelerometer is mounted at various locations on a helicopter. It is a device that measures inertial (i.e.) acceleration forces. Then, the test is conducted by using the two datasets and classifiers; neurofuzzy for Fisher’s and two individual classifiers for Westland’s data set respectively. A classifier is basically a discrete-valued function that is used to assign class labels to particular data points. So, the results showed that neurofuzzy classifier was more effective and efficient.

Crack detection mainly involves two parameters, namely, depth of crack and size of crack. The model mentioned above uses a method with the help of hybrid neural networks to determine the exact location of the crack by using the values of the eigenfrequencies.

Hybrid techniques can almost be applied everywhere involving neural networks, genetic algorithms and soft computing techniques. They mainly improve the accuracy of the algorithms and the performance.
7. Case-based Reasoning (CBR)

It is the process of solving new problems by examining the solutions of past problems. CBR is a useful method in almost every field. In engineering, it is used in the process of design and fault detection and diagnosis. Since it is based on already existing solutions, it is easily understandable and applicable.

7.1 Applications of CBR

It is used in improving the design of die in die-casting [30], assembly planning in the process of shipbuilding [31], VR based system for machining fixture [32] in the field of design. It is used in fault diagnosis of injection moulding machine [33], gas turbines [34] and industrial printers [21].

8. Conclusion

The use of various artificial intelligence methods used in various fields of mechanical engineering like fault detection, autonomous vehicles, image processing in vehicles and various other applications were briefly discussed with an aim to understand which method can be applied to what case. Hybrid techniques are suitable for wide variety of applications as they are more effective since they are a combination of two or more AI methods. But they are much more complex compared to the individual AI methods and the coding part of a hybrid network is a time consuming one. ANN is very useful in problem solving and machine learning as their ability to learn by example makes them very flexible and powerful. GP is best suited for quality control in industries. It forms the basis for computer-automated design and hence plays a major role in design processes. Fuzzy logic has been mostly applied in control systems, power engineering, industrial automation and robotics. The use of fuzzy logic is due to its ease of application and its ability to deal with non-linearity and uncertainty. Deep Learning algorithms need not be explicitly told what to do and hence they are used in self-driving/autonomous vehicles. Soft Computing techniques are mainly used in applications where data recovery and decision-making processes are involved. Case-based Reasoning can be used to come up with new solutions with existing solutions in almost any application. Hence, it finds a wide range of use in fields in which solutions are based on existing ones like in design, manufacturing, fault diagnosis, machine assembly, etc.

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