Artificial Intelligence Technology and Engineering Applications

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Abstract – There has been sixty-year development of the artificial intelligence (AI) and the maturation of AI techniques is now leading to extensive applications and industrialization. In this paper, authors review the connotation and evolution of AI techniques and engineering applications. A four-layer framework of the AI technology system is summarized in this paper to help readers understand AI family. Engineering applications of AI techniques have made remarkable progress in the recent years, for instance, applications in fault diagnosis, medical engineering, petroleum industry and aerospace industry. By introducing the state-of-the-art of AI technologies, it can help the researchers in both engineering and science fields get ideas on how to apply AI techniques to solve application-related problems in their own research areas.

Index Terms – Artificial Intelligence (AI), engineering applications, technology framework.

I. INTRODUCTION

Artificial intelligence (AI) that originated from computer science now becomes a fast growing topic in many different fields. The terminology of artificial intelligence was firstly proposed by John McCarthy et al. on Dartmouth Conference in 1956, which was originally inspired by Turing test [1]. Since AI initially refers to the creation of "humanoid" machine, it is hoped to have the ability of human-like perception and cognition and acting in complex environment. However, the definition of intelligence is still relatively vague, AI has not yet formed a unified definition. It is generally believed that AI is a discipline that studies the process of computer simulation of certain human intelligent behaviors such as perception, learning, reasoning, communicating, and acting, etc. [2, 3].

In fact, the general objective mentioned above is still far from realization because of the limitations of technology. Currently, the aim of AI mainly focuses on training machine to do things which humans can do, even in a better and more efficient manner. AI is developed as a powerful tool to make people's life better, lessen workload of humans, and improve work experience as well. Human could thus be released from many repetitive, physical and dangerous tasks.

The development of AI has experienced several ups and downs. After AI was first proposed in 1956, it went into its first golden age of 1956-1974. Many governments invested in this new research area and a lot of research projects and programs related to AI techniques were initiated worldwide during that time. In the late 1970s, AI was hit by its first "winter" (1974-1980). In 1973, British government stopped funding undirected research, subsequently, AI was under pressure. Japanese investors also withdrew funding provided to AI research. Although AI went through hard times, a few of areas were explored, such as logic programming, commonsense reasoning and so on [4].

After 1980, AI became booming again with the incentive of development of expert system. Many expert systems were adopted in the industry and governments were attracted and started to fund AI research. However, in the late 1980s and early 1990s, AI suffered the second AI winter (1987−1993). It seemed that AI machines could not satisfy what people want. Anyway, AI researchers did not give up their efforts and AI kept its development.

In 1990s, the machine learning was proposed and developed very fast. New research booms were fueled one after another in this field, for example, artificial neural network and supported vector machine. Now the most popular method is the deep neural networks, also known as deep learning, which was firstly established by Hinton in 2006 [5].

In addition to deep learning model, the development of big data and high-performance parallel computing chip together help foster the third AI boom. AI is employed to solve complex problems in various fields of engineering, business, medicine, weather forecasting, and becomes more powerful in improving performance of manufacturing and service systems.

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II. A FRAMEWORK OF TYPICAL AI TECHNIQUES

Artificial intelligence is a collective of advanced computation techniques. It not only contains basic techniques of pattern classification, machine learning, knowledge understanding and expression, but also includes the application techniques of image recognition, natural language processing, human-computer interaction, expert system, anomaly detection, and so on.

In this review study, a technology framework of AI is designed as illustrated in Fig. 1, in which AI related techniques are divided into four layers, namely, supporting basic theory layer, AI model or algorithm layer, AI general technique layer and AI application technique layer. This illustration could not thoroughly depict each fields and techniques in AI research, but it will help give an overall view of the structure and main achievements of this technology.

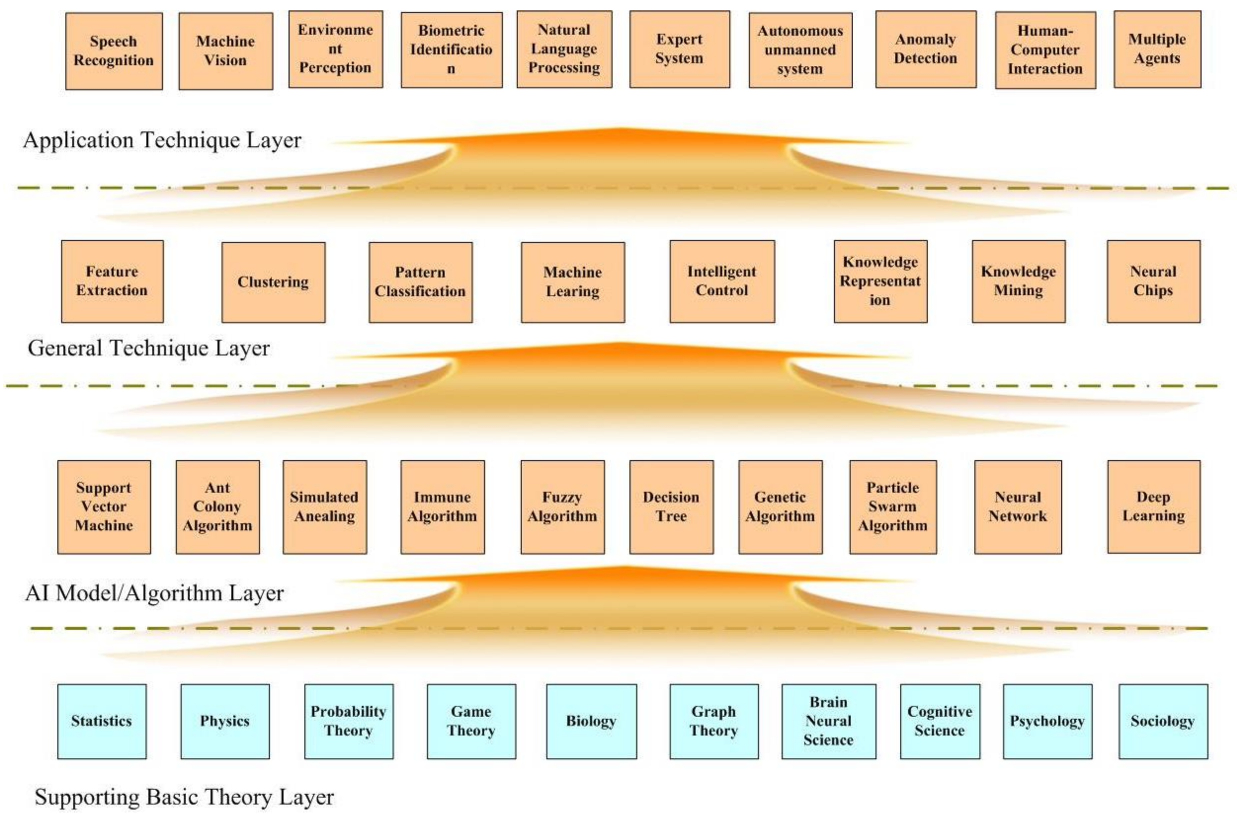

Fig. 1. A framework of typical artificial intelligence techniques.

Artificial intelligence is a typical comprehensive inter-discipline technology whose development was inspired by multiple basic disciplines. Statistics, physics, probability theory, game theory, biology, graph theory, brain neural science, cognitive science, psychology and sociology are all supporting AI development. Some selected techniques in other three layers, which are the main body of AI technology system, will be introduced in the subsections.

2.1 AI models and algorithms

Models and algorithms are fundamental techniques for artificial intelligence, most of which are designed based on scientific findings of the disciplines in supporting basic theory layer, especially statistics, brain neural science or biology. Popular models and algorithms in AI include support vector machine, ant colony algorithm, immune algorithm, Fuzzy algorithm, decision tree, genetic algorithm, particle swarm algorithm, neural network and deep learning.

Support vector machine (SVM) is a typical statistical learning model associated with supervised learning algorithms. SVM is usually used for classification and regression analysis. A SVM training algorithm builds a classification model by finding an optimal hyperplane based on a set of training examples [6, 7]. Support vector machine has been utilized for pattern classification and trend prediction in many application fields, such as power transformer fault diagnosis, disease diagnosis and treatment optimization.

Artificial neural network (ANN) is a representative model of connectionism methodology to realize artificial intelligence. ANN builds mathematical models to imitate natural biological activity from the perspective of brain neural information processing. An artificial neural network usually contains lots of neurons that are connected with each other, and models the mechanism that a biological brain solves problems by using many biological neurons connected by axons. There are various ANN models that have been proposed, such as perceptron, BP neural network, radial basis function (RBF), Hopfield neural network, self-organizing feature map (SOM) etc. [8, 9]. ANN has been employed for both supervised learning and unsupervised learning and has been applied to solve a wide variety of problems.

Deep learning is a newly developed multilayer perception feed forward artificial neural network model that has drawn a lot of attentions in artificial intelligence field [10]. Benefiting from advance in IT environment, especially large amount of available data, we have sufficient computation capacity, and more hidden layers and neurons could be employed to model high level abstractions in data, which could help get closer complicated function and lower optimization difficulty [11].

Another excellent advance of deep learning models is that they need less manual interference, for example, feature selection, weights initialization and network structure learning could be completed with minimum human contribution and less training time as compared with traditional methods. For that reason, deep learning models are not fixed for any specific task, but can be used for more general application.

Great performance of deep learning methods in object recognition competitions gained reputation. Deep learning is now widely used in various fields, in which abstract representation is useful, including speech recognition, bioinformatics, fault diagnosis, drug discovery, genomics, image classification, semantic segmentation, human pose estimation and so on [12, 13].

2.2 Typical AI general techniques

Some AI techniques are not tightly linked with specific applications, but are designed for more general purpose, such as feature extraction, clustering, pattern recognition, machine learning, intelligent control, knowledge representation, knowledge mining and so on.

2.2.1 Feature extraction

Feature extraction or feature selection is the process of selecting the most effective ones from large number of original features, constructing the feature vector for pattern recognition and modeling. One important function of feature extraction is to reduce the resources requirement for describing a large set of data. Extracted features contain sufficient information but are more non-redundant. Feature extraction could optimize the subsequent modeling processes, and bring better human interpretations in some cases. Many methods of feature extraction have been proposed, for example, linear transformation, principal components analysis (PCA), linear discriminant analysis (LDA), wavelet analysis and so on [14,15]. The selection of feature extraction method could affect the ultimate performance in AI applications such as face recognition and speech recognition.

2.2.2 Pattern recognition

Pattern recognition focuses on identifying specific patterns or regularities in data, which enables AI to make judgment like human. Bayesian classification, decision tree, linear discriminant function method, neighborhood classification method, nonlinear mapping method are frequently used in pattern recognition [16]. The subjects in pattern recognition include voice waveform, seismic wave, ECG, EEG, photos, text, symbols, biosensors and other objects, for example, computer-aided diagnosis (CAD) systems, using pattern recognition approaches, have the potential to assist radiologists in the detection and classification of breast cancer [17].

2.2.3 Machine learning

Machine learning refers to the AI technology that can enhance the performance of AI system only depending on data without following the instructions of the program. Supervised learning, unsupervised learning, and semi supervised learning are three main types of machine learning according to mode of learning [18]. Machine learning is a way of intelligent lifting of AI system and is the supporting technology of many AI applications, so machine learning has developed as the mainstream in research of artificial intelligence. Great endeavors are made currently by many top AI researchers to enhance the ability of machine learning through various methods, such as transfer learning, small sample learning, reinforcement learning, interactive learning, open learning and so on [19 20].

2.2.4 Knowledge mining

Knowledge mining is the computational process of discovering underlying knowledge from a huge amount of data and makes it understandable for further use [21]. Knowledge mining is to search for hidden information through automatic or semi-automatic algorithm, such as association rule mining, sequential pattern mining. It could be used in customer relationship management, merchandise recommendation, marketing decision and so on [22].

2.3 Typical AI application techniques

There are a series of application-oriented AI techniques, which are designed to meet specific intelligent demands. Typical AI application techniques include speech recognition, machine vision, environmental perception, biometric identification, natural language processing, expert system, trend prediction, anomaly detection, human-computer interaction, multiple agents and so on.

2.3.1 Speech recognition

Many research efforts have been put on the AI technology that can improve the experience of human-computer interaction, among which speech recognition is one of the most useful techniques. It transcribes human speech into text automatically and accurately [23]. AI general techniques of feature extraction and pattern recognition play important role in speech recognition. Other techniques are also needed, such as the description of sound and acoustic model that appears in a particular sequence and language [24].

2.3.2 Natural language processing

Teaching computer to understand from text, especially from natural language, is one of the most attractive and also most challenging tasks for AI researchers. Natural language processing (NLP) refers to an AI technique that has text processing ability like a human, for example, to extract main ideas or semantic meaning from the text that is readable, natural and grammatical. With help of NLP, an AI system could communicate with people through language to answer questions and also could learn from text to accumulate knowledge by itself. Machine learning, pattern recognition and knowledge computing are frequently used in natural language processing research [25].

2.3.3 Machine vision

Machine vision technique refers to the ability of a computer that can recognize objects, scenes, and activities from an image or video. In machine vision research, the large image analysis tasks are usually broken down into multiple controllable tasks, which can be handled by various AI general techniques. For example, some feature extraction techniques can detect edge and texture of objects from the image. Patent classification techniques can be used to determine whether the identified features represent a class of objects known to the system. Machine learning is also one of the main research methods in machine vision. It can improve the ability of object recognition by training and improving the visual model [26]. Machine vision technique has wide application fields such as robotics, intelligent factory, fault detection, security monitoring system, etc. [27, 28].

2.3.4 Expert system

Research of expert system started in the early stage of artificial intelligence development, which simulates the problem solving and reasoning ability of human experts by designing intelligent models and algorithms. It follows a knowledge driving methodology that realizes intelligence by embedding human knowledge and experience in AI system. In the past several decades, researchers have scored remarkable achievements in this field such as automatic theorem proof and medical diagnosis [29, 30]. Nowadays, this technique gets fast development with the application to knowledge engineering projects in many fields. Knowledge acquisition, human-computer interaction, knowledge representation, reasoning and decision are key techniques in designing of expert system.

2.3.5 Anomaly detection

There are widespread needs in real world, especially in engineering field, for anomaly detection technology. Compared with expert system, anomaly detection technique is a data driven AI method whose performance rely heavily on feature extraction and pattern recognition of the data. There is usually abnormal signal in monitoring data before the fault of operating machines arising, which is so weak that is hard to be noticed by people. In banking sector, insurance and investment trading, mistakes are often made by investors due to their human shortcomings, emotions, and biases. When network crime is ongoing, there is also signal that could be detected. AI has advantage in this area by utilizing pattern classification and machine learning methods.

III. APPLICATIONS OF AI TECHNOLOGY IN ENGINEERING FIELD

As an enabling technology, AI could reconstruct the mode of production, distribution, exchange and consumption in real economy, especially in engineering field. AI technology not only has advantage in reducing cost, improving efficiency and ensuring safety, but also could provide machine with man-like ability to reduce labor intensity of workers. Broad application scenes such as environmental perception, fault diagnosis, biometrics, medical diagnosis, intelligent control have attracted much research attention and many successful industrial applications have been realized.

3.1 AI in power industry

Ensuring device health is a key issue in power industry because heavy loss might be caused due to unnecessary interruption and downtime induced by an even small device fault. Many research efforts have been made to utilize AI techniques in fault diagnosis such as power transformer fault diagnosis and machinery fault diagnosis.

Tran et al. [31] proposed an approach based on decision trees and adaptive neuro-fuzzy inference to diagnose fault of induction motor. Feng et al. [32] proposed a deep neural networks (DNNs) to diagnose rotating machinery, which could extract available fault characteristics and classify fault types accurately. Samanta et al. [33] used the ANNs and SVM methods to diagnose faults of bearings. Fisher [34] applied AI to failure detection system and introduced a fault detection approach that is advanced in processing flawed data. Fischer applied the approach in many fields of power industry, such as static security assessment of electric power systems, oil leak detection in underground power cables and the stator overheating detector.

Souahlia et al. [35] presented an AI approach to conduct fault classification for power transformer dissolved gas analysis (DGA). The AI techniques used in DGA include fuzzy logic, ANN and support vector machine classifiers. Ismail et al. [36] introduced ANN and genetic algorithms into fault detection and diagnosis to establish intelligent monitoring systems in power plant. Song et al. [37] designed a fault diagnosis system based on machine vision technique. The fault diagnosis system was used for a heliostat field of a solar power plant to detect the fault heliostats in a large field.

3.2 AI in medical engineering

Medical diagnosis is a process of both knowledge intensity and experience intensity. A tiny change in medical image or medical signal is hard to be recognized by human eyes. It is usually not easy for doctors especially juniors to give an accurate diagnosis. Advances in image recognition and pattern recognition contribute to medical diagnosis based on medical image, EEG, MRI-based image data, and even speech data.

Stoitsis et al. [38] introduced a fuzzy c-means method and genetic algorithm based method to extract features from medical images. They testified AI technology to be a very useful tool in medical diagnosis for accurate quantitative analysis and qualitative evaluation of medical data. Magnetic resonance imaging (MRI) is an important diagnostic tool for early detection of cancer. Machine vision techniques have been used in deciding whether a given tumor is benign or malignant by MRI image recognition [17]. Deep learning methods can also be efficient when processing MRI-based image data to classify breast lesions [39].

AI has been applied in risk stratification of cardiovascular diseases. Zygmunt et al. [40] introduced a system based on ANN to make diagnosis of brain dysfunctions through assessment of speech quality of patient suffering from speech motor disorder. Adeli et al. [30] designed a fuzzy expert system to diagnose heart disease by employing 13 medical data as inputs, like chest pain type, blood pressure, cholesterol, maximum heart rates et al., and the output of the system is the possibility one may suffer from heart disease. Sikchi et al. [41] proposed a fuzzy expert system that be used for liver disease diagnosis using fuzzy model.

3.3 AI in petroleum industry

AI technology application in petroleum industry has also made notable progress these years. Different AI techniques have been utilized to optimize drilling operations or give an earlier detection of oil-spill in oil fields. AI systems have been testified superior than traditional methods, such as hardware based methods and biological methods.

Manshad et al. [42] proposed a two-model method to optimize drilling penetration rate based on feed forward two-layer perception neural network. The first model is proposed to choose the drilling bit and the second model is designed to predict the maximum drilling penetration rate. The models proved much efficient and accurate for optimization of drilling penetration rate. Singha et al. [43] demonstrated that Neural Networks can be used in oil spill classification systems based on image segmentation and feature classification. The approach they proposed uses two different ANNs. One is used to segment SAR images to identify pixels form oil features and the other to classify objects into oil spills based on their features.

Leak location and leak rate are two main factors that need to be taken into consideration in the process of detection of pipeline leaking. Sukarno et al. [44] developed a transmission pipeline model and leak detection model to recognize patterns of pressure distribution using ANN. After training, the artificial neural network model can predict the position of leak based on input information.

3.4 AI in aerospace industry

There are many complex tasks in aerospace industry, which are well suited for the AI technology to complete. The applications of AI in aerospace field include diagnosis for aero-engine, wear condition aid design for aircraft, optimization of key parameter of aerospace alloy and so on.

In the process of preliminary designing aircraft, various disciplines should be involved, such as aerodynamics, structure and propulsion. These different disciplines are related to each other and should be satisfied simultaneously. Oroumieh et al. [45] introduced AI models into aircraft design. Their work demonstrated that fuzzy logic and neural network can aid selecting suitable association of key parameters of aircraft, and the AI tools were effective to reduce aircraft design cycle time.

Ma et al. [46] constructed an immune algorithms based method to diagnose the wear condition of aero-engine. Negative selection principle was used, and the detectors were trained by using fault samples data. Three types of wear faults were detected, including gear overload fatigue, wear of bearing fatigue and gear agglutination or scratches. AI models can also be used to optimize key parameter of aerospace alloy. Devarasiddappa et al. [47] applied ANN model to predict the surface roughness in wire-cut electrical discharge machining of aerospace alloy.

IV. CONCLUSIONS

The new generation of information technology, represented by AI, might induce a new round of technological revolution. As a typical enabling technology, the maturation and application of AI technology lead to extensive penetration into other important industries of national economy, and will change transportation, manufacturing, medical care, business, and other industry over time.

A review on artificial intelligence technology is given in this study. We established a technology framework of four layers including theory, model and algorithm, general technology and application technology. This framework would be helpful to obtain a clear understanding of relations between various AI techniques, especially helpful for researchers of other fields. Artificial Intelligence techniques have already been applied in a variety of fields. The study summarizes some examples of AI applications in industry, including power industry, medical engineering, petroleum industry, and aerospace industry. Some of these applications have achieved surprising results.

Furthermore, today's successful of artificial intelligence attributes in some degree to the growth of many supporting technologies, such as internet of things, sensor, and big data, which also advanced at high speed in recent years. We believe that along with further maturation of AI and related technique cluster, application of artificial intelligence would be widely extended in the near future.

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