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FUZZY, NEURAL NETWORK AND EXPERT SYSTEMS METHODOLOGIES AND APPLICATIONS-A REVIEW

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The rapid growth in the field of artificial intelligence from past one decade has a significant impact on various application areas i.e. health, security, home appliances among many. In this paper we aim to review artificial intelligence methodologies and their potential applications intended for variable purposes i.e. Agriculture, applied sciences, business, engineering, finance, management etc. For this purpose articles from past one decade (from 2004 to 2013) are reviewed in order to explore the most recent research advancements in this domain. The review includes 172 articles gathered from related sources including conference proceedings and academic journals. We have categorized the selected articles into four main categories i.e. fuzzy systems, neural network based systems, neuro fuzzy systems and expert systems. Furthermore, expert systems are further classified into three categories: (i) rule based expert systems, (ii) knowledge based expert systems and (iii) intelligent agents. This review presents research implications for practitioners regarding integration of artificial intelligence techniques with classical approaches and suggestions for exploration of AI techniques in variable applications.

Key words: Literature survey, Artificial intelligence methodologies, Fuzzy systems, Neural network, Expert systems

1 Introduction

Over the past few decades, Artificial intelligence (AI) techniques have been extensively used in various fields and have replaced classical techniques by incorporating intelligent behavior of user to solve complex and challenging problems [1]. The basic idea behind AI techniques is the perfect embodiment of the blend of human experience, task-specific knowledge and computational intelligence and processing. AI techniques can be categorized in two ways such as: according to the form of the knowledge (either structured or unstructured); and the way in which this knowledge is processed (either symbolic or numerical) as shown in Figure 1.

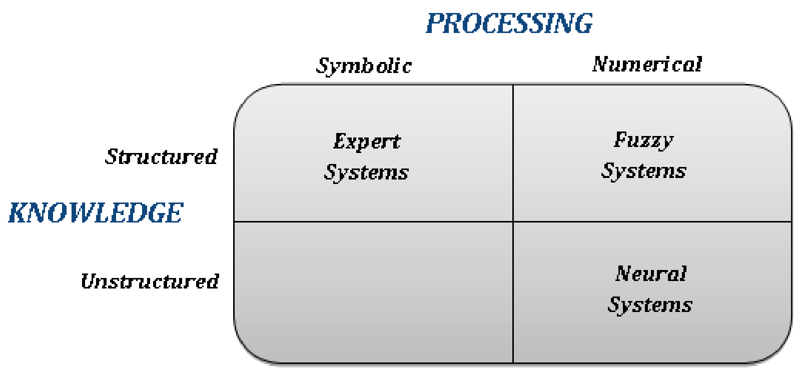

Figure 1 Classification of AI techniques [2]

AI techniques provide correctness, robustness, extendibility and reusability for solution of various problems where conventional methods have proven insufficient[2]. Hence rapid growth in the use of AI techniques has been observed in many areas of science, engineering, industry and societal processes. Though modern AI was formally introduced in 1956 but the last decade has witnessed so many important advancements and innovations in artificial intelligence at a rapid pace that have had a significance impact on almost all application areas. Reasons for this phenomenon are threefold:

1. Correctness and robustness offered by AI methodologies
2. Increase in computational power and application area
3. Gradual increase in access to online technical resource

This paper surveys AI techniques (fuzzy, neural network and expert systems methodologies) and applications, developed in the last decade to explore application areas of each methodology and draw implications for future research and development. The survey can be regarded as an extension of the previous work done in the AI domain [3], [4]. Since that survey was for the period 1995-2004 and it included all expert systems techniques however some of them are now being used in combination of other techniques so there was need for an updated survey with techniques used in almost every application area

This review survey is based on articles from 2004 to 2013.The retrieved articles were searched in electronic resources like Elsevier, Emerald, EBSCO, IEEE Xplore, Wiley online databases as well as several online journals and conference proceedings. Initially more than 1000 articles relevant to the topic were scanned, later only 172 were selected based on their relevancy with the research theme and novelty of ideas and implementation. This paper surveys four methodologies of AI techniques based on [2]: fuzzy systems, neural network based systems, neuro fuzzy systems and expert systems, along with their application for different research domains. Besides fuzzy and neural network based systems, expert systems are classified using nine categories [3]: rule-based systems, knowledge-based systems, object-oriented methodology, case-based reasoning, system architecture development, intelligent agent systems, modeling, ontology and database management but only rule based expert systems, knowledge based expert systems and intelligent agents are considered in this survey. The reason is that major contribution in expert systems during the last decade falls in selected categories.

The rest of the paper is structured as follows: Sections 2-5 present survey results of fuzzy, neural and expert system methodologies and their applications. Section 6 contains research trends and future development in these AI techniques. In last section, concise conclusion is presented.

2 Fuzzy Systems and their Applications

Fuzzy system uses fuzzy logic, introduced by Zadeh in [5]. Since its introduction, fuzzy systems have had successful applications in many diverse fields for solution of generic and specific problems. Conventionally decision making in computers was rigid (yes-no, true-false, 0-1). On the contrary, fuzzy systems provide flexibility in decision making through incorporation of fuzzy sets and rules (allow graduation from true to false, yes to no and 0 to 1). This kind of decision making enables computers to imitate human reasoning. The technique is applied in situations where decision or conclusion is not matter of yes or no (true or false, 0 or 1) and often involve several degrees between yes and no.

Some of applications implemented by fuzzy based systems are such as fault diagnosis in electric systems, medical diagnosis/treatment, nonlinear system control, software engineering, unmanned air vehicles control, wastewater management, decision making, fuzzy control system design, mobile robot navigation, object tracking, pattern recognition, robot kinematic solution, robot manipulator control, supply chain management, twin rotor system control, fault detection, intrusion detection, risk management, flood frequency analysis and stock forecast. The methodologies of fuzzy based systems along with their applications are listed in Table 1.

Table 1Fuzzy systems and applications

Fuzzy systems/applications	**Authors**
Fault diagnosis in electric systems	[6], [7]
Medical diagnosis/treatment	[8], [9], [10]
Nonlinear system control	[11], [12]
Software engineering	[13], [14]
Unmanned air vehicles	[15], [17]
Wastewater management	[16], [17]
Decision making	[18], [19]
Fuzzy control system design	[20], [21]
Mobile robot navigation	[22], [23]
Object tracking	[24], [25]
Pattern recognition	[26], [27]
Robot kinematic solution	[28], [29]
Robot manipulator	[30], [31]
Supply chain management	[32], [33]
Twin rotor system	[34][35]
Fault detection	[36]
Intrusion detection	[37]
Risk management	[38], [39]
Flood frequency analysis	[40], [41]
Stock forecast	[42], [43]

3 Neural Networks based Systems and their Applications

Artificial neural network (ANN) is a computational model that emulates biological neurons. ANN was proposed in the 1940s but due to technical limitations could not be implemented until the 1980s. ANNs are made up of parallel layers of nodes (neurons) which are interconnected with varying weights (synaptic weights) [2]. The nodes receive input that are analogous to the electrochemical impulses that dendrites of biological neurons receive from one-another. The output of node is analogous to signal sent out from neuron over its axon. Various network architectures have been proposed according to nature of applications. ANN has distributed architecture which is extremely suitable for parallel processing and it has ability to learn on-line as compare to other methodologies [2].

The applications using neural network based systems include fault diagnosis, industrial and process control, robot kinematic solution/control, support vector machine learning, EEG signal classification/detection, nonlinear system control, pattern recognition, medical diagnosis/treatment, agriculture, exchange rate forecasting, object recognition, software project management, industrial PID controller, mobile robot navigation, robot manipulator control, unmanned air vehicles control and twin rotor system control. The methodologies of neural network based systems along with their applications are listed below in Table 2.

Table 2Neural Network based systems and applications

Neural Network based systems/applications	Authors
Fault diagnosis	[44], [45]
Industrial and process control	[46], [47]
Robot kinematic solution/control	[48], [49]
Support vector machine learning	[50], [51]
EEG signal classification/detection	[52], [53]
Nonlinear system control	[54]
Pattern recognition	[55], [56]
Medical diagnosis/treatment	[57], [58]
Agriculture	[59]
Exchange rate forecasting	[60], [61]
Object recognition	[62], [63]
Software project management	[64], [65]
Industrial PID controller	[66], [67]
Mobile robot navigation	[68], [69]
Robot manipulator	[70], [71]
Unmanned air vehicles	[72], [73]
Twin rotor system	[74]
Computer Games	[75], [76]

4 Neuro Fuzzy Systems and their Applications

Fuzzy systems proved effective in dealing with problems that cannot be solved through conventional approaches. However there are several applications for which extraction of suitable collection of fuzzy rules from available data set is still a challenge i.e. fuzzy membership function type and fuzzy rules are determined using trial and error by users [2]. Researchers have so far tackled this problem by designing fuzzy systems with combination of neural network (e.g. [77]). Because the neural network learning algorithms can be used to identify the parameters of fuzzy systems, the resulting neuro-fuzzy system offers the strength of both methodologies while overcoming some of the limitations of individual techniques.

Some of application areas based on neuro fuzzy systems are hydrology, intrusion detection, nonlinear system control, pattern recognition, EEG signal classification, object recognition, robot manipulator control, mobile robot navigation, medical diagnosis/treatment, fault diagnosis, induction motor control, software engineering, agriculture, inverted pendulum systems, stock market, HVAC, Twin rotor system control, wastewater management, CMOS circuits modelling & simulation, unmanned air vehicles and robot kinematic solution/control. The methodologies of neuro fuzzy systems along with their applications are listed below in Table 3.

Table 3 Neuro fuzzy systems and applications

Neuro Fuzzy systems/ applications	**Authors**
Hydrology	[78], [79]
Intrusion detection	[80], [81]
Nonlinear system control	[82], [83]
Pattern recognition	[84], [85]
EEG signal classification	[86], [87]
Object recognition	[88], [89]
Robot manipulator	[90], [91]
Mobile robot navigation	[92], [93]
Medical diagnosis/treatment	[94]
Fault diagnosis	[95], [96]
Induction motor control	[97], [98]
Software engineering	[99], [100]
Agriculture	[101]
Inverted pendulum systems	[102], [103]
Stock market	[104], [105]
HVAC	[106]
Twin rotor system	[107], [108]
Wastewater management	[109], [110]
CMOS circuits modeling & simulation	[111]
Unmanned air vehicles	[112]
Robot kinematic solution/control	[113], [114]

5 Expert Systems and their Applications

Expert systems are programming methodologies, designed to emulate human expert skills by making extensive use of specialized knowledge to solve problems [2]. The term emulate is used in sense that expert systems are intended to act like human experts in all respects. Expert systems can also be defined as combination of knowledge and inference. Experts systems offer advantages of fast response, intelligent data base, increased availability and performance and reduced cost and danger. From half of a century, experts systems have been successfully employed in business, medicine, economics, science and engineering. The three main categories of expert systems are

1. Rule-based expert systems
2. Knowledge-based expert systems
3. Intelligent agents

5.1. Rule-based Expert Systems

Rule-based expert system is defined as an automated system which contains information as an encoded human expert's knowledge. The information consists of a set of IF (condition)-THEN (action) rules, a set of facts and some interpreter, providing given facts, controlling the implementation of the rules [115] . The rules are applied on some data for inference of results to reach a suitable conclusion. Computer software or routines are used as inference mechanism in order to deduce rational results from set of rules and facts and formulate conclusion.

Table 4 Rule based expert systems and applications

Rule-based expert systems/applications	**Authors**
Distribution planning	[116]
Geosciences	[117]
Knowledge representation	[118]
Sensor control	[119]
Tutoring system	[120]
Haptic devices modelling	[121]
Knowledge acquisition	[122]
Medical treatment	[123], [124]
Fault diagnosis	[125], [126]
Topological observation	[127]
Intrusion detection system	[128]
Online learning system	[129]
Pipeline leak detection	[130]
Translation	[131], [132]
Maritime surveillance	[133]
Project scheduling	[134]
Chemical reactions	[135]
Agriculture	[136]
Electrical distribution	[137]
Oil fields	[138]
Algebraic problem solving	[139]

Some of application areas using rule-based expert systems are geosciences, sensor control, distribution planning, tutoring system, knowledge representation, haptic devices modelling, knowledge acquisition, medical treatment, topological observation, fault diagnosis, online learning system, intrusion detection system, translation, pipeline leak detection, maritime surveillance, project scheduling, chemical reactions, electrical distribution, agriculture, oil fields and algebraic problem solving. Rule-based expert systems methodologies and their applications are summarized in Table 4.

5.2. Knowledge-based Expert Systems

Knowledge based expert systems (KBS) are computer software that use a knowledge base to solve problems in different complex environments. KBS are different as compare to conventional computer software in a manner that knowledge is encoded explicitly via tool rather than implicitly via code. The essential components of KBS are user interface, inference engine and knowledge base. The user supplies some information or facts to KBS and receives expertise in response. The inference engines use the knowledge encoded in knowledge base to draw conclusions. The knowledge base is required to grow and change as knowledge is added. Today, a wide range of knowledge-based expert systems have been built and successfully deployed.

Some application areas employing knowledge-based expert systems are robotics, strategic planning, building architecture design, defence budget planning, supply chain system, fault diagnosis, medical treatment, agricultural management, performance evaluation, stock trading, bioinformatics, decision support, image processing, process Industries, molecular biology, risk management and storm water management. Knowledge-based expert systems and their applications are listed in Table 5.

Table 5 Knowledge-based expert systems and applications

Knowledge-based expert systems/applications	**Authors**
Robotics	[140], [141]
Strategic planning	[142]
Building architecture design	[143]
Defence budget planning	[144]
Supply chain system	[145]
Fault diagnosis	[146], [147]
Medical treatment	[148],[149]
Agricultural management	[150]
Performance evaluation	[151]
Stock trading	[152]
Bioinformatics	[153]
Decision support	[154], [155]
Image processing	[156], [157]
Process Industries	[158]
Molecular biology	[159]
Risk management	[160]
Storm water management	[161]

5.3. Intelligent Agents

Intelligent agents are computer software routines and are also named as wizards, software agents and multi-agents (turban). An intelligent agent is computer software that is capable of flexible autonomous action in a defined environment in order to meet its design objectives [162]. Intelligent agents are reactive (able to perceive their environment and respond in a timely manner), pro-active (able to exhibit goal-directed behavior by taking the initiative) and social-able (able to interact with other agents or humans) in order to satisfy their design objectives.

Some of application based on intelligent agents are agricultural decision support, building architecture design , knowledge representation and management, stock prediction system, supply chain system, decision support, system analysis and design, anti-money laundering, tutoring system, web-based education system, adaptive learning system and power grid control. Intelligent agents based systems and their applications are summarized in Table 6.

Table 6 Intelligent agents and applications

Intelligent agents/applications	**Authors**
Agricultural decision support	[163]
Building architecture design	[164]
Knowledge representation and management	[165]
Stock prediction system	[166]
Supply chain system	[167], [168]
Decision support	[169]
System analysis and design	[170], [171]
Anti-money laundering	[172]
Tutoring system	[173], [174]
Web-based education system	[175]
Adaptive learning system	[176]
Power grid control	[177]

6 Discussion

Fuzzy, neural and expert systems have diverse applications in today’s world. The comprehensive research domain finds its applications in almost every field. The aim of this review was to explore the diverse applications of the aforementioned techniques and presenting some suggestions for improvement in existing solutions. The methods and their respective applications presented in this review do not cover all of the fields yet the most cited and applied work in this domain is selected for review. The applications are classified according to the problem domain.

In this review, we have covered the application domains of the neural, fuzzy and expert systems techniques such as agriculture, aerospace, biochemistry, bioinformatics, biomedical, biology, chemistry, computer science, education, economics, energy engineering, hydrology, health care, HVAC, image processing, metallurgy, mathematics, mechanical, medical, management sciences, oil fields, power systems, robotics and water resources. A Comparison among some application area is given in Table 7.

Table 7 Comparison of Application areas

Application Ares	**Fuzzy**	**Neural**	**Neuro Fuzzy**	**Rule based ES**	**KB ES**	**Intelligent agents**
Agriculture	√	√	√	√	√	√
Control system design	√	√	√			
Decision making	√	√	√	√	√	√
Fault diagnosis	√	√	√	√	√	√
Flight Control	√	√	√			
Flood frequency analysis	√	√	√			
Image Processing	√	√	√		√	√
Intrusion detection	√	√	√	√	√	√
Medical Sciences	√	√	√	√	√	√
Nonlinear Control	√	√	√			
Risk management	√	√	√	√	√	
Robotics	√	√	√	√	√	
Software engineering	√	√	√	√	√	√
Stock forecast	√	√	√	√	√	√
Supply chain management	√	√	√		√	√

In the above table, empty fields shows that particular methodology is rarely or never used in the corresponding application area. It is clear that applications in several domains i.e. robotics, image processing, fault diagnosis have employed several methodologies to provide solutions e.g. for a problem of unmanned air vehicles control fuzzy control, neural network control and neuro fuzzy control are implemented, yet not implemented in knowledge based expert systems and rule based expert systems. This shows that each of the methodologies has its own limitations and suitability criteria that make one methodology not suitable for all applications. Moreover, it can be analyzed from the review results that the authors use problem solving techniques based on their academic background and expertise. For instance fault diagnosis has been done almost with every technique. This shows that several problems can be solved with multiple techniques and the preference factors can be many including problem solvers' expertise and knowledge of the area.

The review revealed that some of the methodologies share common concepts and thus have been used in combination for several applications. For instance fuzzy systems, rule based expert systems and knowledge based expert systems have similar concepts in contrast to neural network based systems. However despite of similarity in concepts, some applications are not yet capable to be handled by these similar techniques. This shows that the selection of technique for problem solution depends on other factors than the suitability of technique including problem solving technique's viability. For example fuzzy, neural and neuro fuzzy techniques are widely used for nonlinear system control but rule based expert systems and intelligent agents techniques have rarely used for this domain because these techniques are not viable. Therefore the review results unfold that in order to find solution of a problem with the help of AI techniques requires some problem solver's expertise, his/her background knowledge of the application domain and of that methodology, and the technique's viability for the domain.

7 Limitations

This survey is intended to summarize the advances made in fuzzy, neural network and expert systems methodologies and applications for the last one decade. Several limitations of this work are discussed below.

The basic limitation of any review is the bias in the selection of studies and the possible imprecision in data extraction from the variable sources. The categorization with respect to methodologies and their respective application area was an intricate task so in that context, it might have been possible that some of the potential studies were missed which might have been included to draw more conclusions.

Furthermore keyword index was used for search, so any published work without these keywords might have been missed regardless of its relevance with the topic.

Another, limitation in this domain was the language of publications. This survey has not included articles from non-English resources due to researchers' lack of comprehension of other languages. It has been come across during the extensive study search that huge amount of work done in this domain is published in other languages (such as Chinese mandarin, German and Russian). Therefore, including the studies published in English language only has limited the scope of this study

8 Suggestions & Implications

Some suggestions and implications are presented here.

Integration of different AI techniques. Artificial intelligence is a broad field and several techniques have been developed so far for various problems and research domains. Therefore it is essential for development of new AI techniques that different techniques must be integrated for different research domains. It will widen the domain of AI techniques as well as many challenging problem shall be solved.

Fusion of AI techniques with classical approaches. In study of some applications it is found that enhanced performance was obtained when these techniques were fused with classical techniques. For example neural network based sliding mode control (nonlinear control technique) of robotic manipulator is more efficient than neural network control of robotic manipulator.

Adaption of Innovation. Innovation is a key of technological evolution. For the development of AI techniques it necessary to learn and share, apply new ideas in different fields, adapt new problem solving techniques and make use of advancement in a technique in diverse applications.

9 Conclusion

This paper reviews the applications of AI techniques i.e. fuzzy, neural and expert systems methodologies for the last one decade (2004-2013). The survey is based on the articles selected from various online databases, conference proceedings and literature studies. The aforementioned AI methodologies are classified with respect to their research and applications domains. The review revealed that the AI techniques have found their applications in diverse field including health, agriculture, home appliances, and education among many. It is concluded that problem solving using a specific technique depends upon expertise and background knowledge of the problem solver, and viability of the technique. This proves that not every technique is suitable for solving multiple problems. Moreover, it is also suggested that fusion of AI techniques with classical approach may result in a broader research domain and widen application domain of these techniques. Finally innovation is essential for evolution of these techniques and has been the key for the development so far.

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