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Expert system methodologies and applications—a decade review from 1995 to 2004

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Abstract

This paper surveys expert systems (ES) development using a literature review and classification of articles from 1995 to 2004 with a keyword index and article abstract in order to explore how ES methodologies and applications have developed during this period. Based on the scope of 166 articles from 78 academic journals (retrieved from five online database) of ES applications, this paper surveys and classifies ES methodologies using the following eleven categories: rule-based systems, knowledge-based systems, neural networks, fuzzy ESs, object-oriented methodology, case-based reasoning, system architecture, intelligent agent systems, database methodology, modeling, and ontology together with their applications for different research and problem domains. Discussion is presented, indicating the followings future development directions for ES methodologies and applications: (1) ES methodologies are tending to develop towards expertise orientation and ES applications development is a problem-oriented domain. (2) It is suggested that different social science methodologies, such as psychology, cognitive science, and human behavior could implement ES as another kind of methodology. (3) The ability to continually change and obtain new understanding is the driving power of ES methodologies, and should be the ES application of future works.

Keywords: Expert systems; Expert system methodologies; Expert system applications; Literature survey

1. Introduction

Expert systems (ES) are a branch of applied artificial intelligence (AI), and were developed by the AI community in the mid-1960s. The basic idea behind ES is simply that expertise, which is the vast body of task-specific knowledge, is transferred from a human to a computer. This knowledge is then stored in the computer and users call upon the computer for specific advice as needed. The computer can make inferences and arrive at a specific conclusion. Then like a human consultant, it gives advices and explains, if necessary, the logic behind the advice (Turban & Aronson, 2001). ES provide powerful and flexible means for obtaining solutions to a variety of problems that often cannot be dealt with by other, more traditional and orthodox methods. Thus, their use is proliferating to many sectors of our social and technological life, where their applications are proving to be critical in the process of decision support and problem solving.

As a part of ES research, this paper surveys the development of ES through a literature review and classification of articles from 1995 to 2004 as a basis, exploring the ES methodologies and applications during that period. The reason for choosing this period is that the Internet was opened to general users in 1994 and this new era of information and communication technology has played important roles, not only in the field of ES, but also in the ability to collect data from online database. This literature survey started on March 2003 and it was based on a search in the keyword index and article abstract for 'ES' on the Elsevier SDOS, IEEE Xplore, EBSCO (electronic journal service), Ingenta, and Wiley InterScience online database, for the period from 1995 to 2004, in which 10,439 articles were updated and found on June 2004. After topic filtering, there were 166 articles from 78 journals related to the keyword 'ES applications', 98 of which were connected to the methodology of keyword 'ES methodology'. Based on the scope of 166 articles on ES applications, this paper surveys and classifies ES methodologies using eleven

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categories: rule-based systems, knowledge-based systems, neural networks, fuzzy ESs, object-oriented methodology, case-based reasoning (CBR), system architecture development, intelligent agent (IA) systems, modeling, ontology, and database methodology together with their applications for different research and problem domains.

The rest of the paper is organized as follows. Sections 2–12 present the survey results of ES methodologies and applications based on the above categories, respectively. Section 13 presents some discussion, extending to suggestions for future development of ES methodologies and applications. Finally, Section 14 contains a brief conclusion.

2. Rule-based systems and their applications

A rule-based ES is defined as one, which contains information obtained from a human expert, and represents that information in the form of rules, such as IF–THEN. The rule can then be used to perform operations on data to inference in order to reach appropriate conclusion. These inferences are essentially a computer program that provides a methodology for reasoning about information in the rule base or knowledge base, and for formulating conclusions. Applications of rule-based systems on ESs are including: state transition analysis, psychiatric treatment, production planning, advisory system, teaching, electronic power planning, automobile process planning, hypergraph representation, system development, knowledge verification/validation, alcohol production, DNA histogram interpretation, knowledge base maintenance, scheduling strategy, management fraud assessment, knowledge acquisition, knowledge representation, communication system fault diagnosis, bioseparation, material processing design, resource utilization, biochemical nanotechnology, probabilistic fault diagnosis, agriculture planning, load scheduling, apiculture, tutoring system, geoscience, and sensor control. The methodology of rule-based systems and their applications are categorized in Table 1.

Table 1
Rule-based systems and their applications

Rule-based systems/applications	Authors
State transition analysis	Ilgun, Kemmerer, and Porras (1995)
Psychiatric treatment	Goethe and Bronzino (1995)
Production planning	Hamada, Baba, Sato, and Yufu (1995)
Advisory system	Kose et al. (1995)
Teaching	Chan, Ma, Chan, and Chen (1995)
Electronic power planning	Rahman and Hazim (1996)
Automobile process planning	Sabourin and Villeneuve (1996)
Hypergraph representation	Ramaswamy, Sarkar, and Chen (1997)
System development	Mulvaney and Bristow (1997)
Knowledge verification/validation	Wu and Lee (1997)
Alcohol production	Guerreiro et al. (1997)
DNA histogram interpretation	Marchevsky, Truong, and Tolmachoff (1997)
Knowledge base maintenance	Higa and Lee (1998)
Scheduling strategy	Zupan and Cheng (1998)
Management fraud assessment	Deshmukh and Talluru (1998)
Knowledge acquisition	Wu and Chen (1999)
Communication system fault diagnosis	Leon, Mejias, Luque, and Gonzalo (1999)
Bioseparation	Lienqueo, Salgado, and Asenjo (1999)
Material processing design	Kim and Im (1999)
Resource utilization	McCoy and Levary (2000)
Biochemical nanotechnology	Wasiewicz, Janczak, Mulawka, and Plucienniczak (2000)
Probabilistic fault diagnosis	Leung and Romagnoli (2000)
Agriculture planning	Plant and Vayssieres (2000)
Load scheduling	Croce et al. (2001)
Apiculture	Mahaman et al. (2002)
Agricultural diagnostic/advisory	Mahaman, Passam, Sideridis, and Yialouris (2003)
Geoscience	Soh, Tsatsoulis, Gineris, and Bertoia (2004)
Sensor control	Valenzuela, Bentley, and Lorenz (2004)
Tutoring system	Hatzilygeroudis and Prentzas (2004)
Knowledge representation	Hatzilygeroudis and Prentzas (2004)

3. Knowledge-based systems and their applications

The most common definition of KBS is human-centered. This highlights the fact that KBS have their roots in the field of artificial intelligence (AI) and that they are attempts to understand and initiate human knowledge in computer systems (Wiig, 1994). The four main components of KBS are usually distinguished as: a knowledge base, an inference engine, a knowledge engineering tool, and a specific user interface (Dhaliwal & Benbasat, 1996). On the other hand, the term KBS includes all the organizational information technology applications that may prove helpful to manage the knowledge assets of an organization, such as ESs, rule-based systems, groupware, and database management systems (DBMS) (Laudon & Laudon, 2002).

Some of these applications which are implemented by knowledge-based systems include the following: medical treatment, personal finance planning, engineering failure analysis, waste management, production management, thermal engineering, decision support, knowledge management, knowledge representation, power electronics design, framed buildings evaluation, financial analysis, chemical incident management, automatic tumor segmentation, business game, climate forecasting, agricultural management, steel composition design, strategic management, environmental protection, wastewater treatment, decision making and learning, isokinetics interpretation, chemical process controlling, therapy planning, plant process control, outage locating planning, concurrent system design, case validation, chip design, agriculture planning, power transmission protection, crop production planning, tropospheric chemistry modeling, planar robots, and urban design. The methodology of knowledge-based systems and their applications are categorized in Table 2.

Table 2
Knowledge-based systems and their applications

Knowledge-based systems/applications	Authors
Medical treatment	Alonso-Amo, Perez, Gomez, and Montes (1995)
Personal finance planning	Dirks, Kingston, and Haggith (1995)
Engineering failure analysis	Graham-Jones and Mwllor (1995)
Waste management	Wei and Weber (1996)
Production management	Dawood (1996)
Thermal engineering	Afgan and Carvalho (1996)
Decision support	Keefe and Preece (1996)
Knowledge management	Dutta (1997)
Knowledge representation	Mitra and Basu (1997)
Framed buildings evaluation	Lu and Simmonds (1997)
Power electronics design	Fezzani, Piquet, and Foch (1997)
Financial analysis	Matsatsinis, Doumpos, and Zopounidis (1997)
Chemical incident management	Finch and Lees (1997)
Automatic tumor segmentation	Clark et al. (1998)
Business game	Duan, Edwards, and Robins (1998)
Climate forecasting	Rodionov and Martin (1999)
Agricultural management	Girard and Hubert (1999)
Steel composition design	Manohar, Shivathaya, and Ferry (1999)
Strategic management	Volberda and Rutges (1999)
Environmental protection	Gomolka and Orlowski (2000)
Wastewater treatment	Baeza, Ferreira, and Laufuente (2000)
Decision making and learning	Mockler, Dologite, and Gartenfeld (2000)
Isokinetics interpretation	Alonso, Fuertes, Martinez, and Montes (2000)
Chemical process controlling	Barrera-Cortes, Astruc, and Tufeu (2001)
Physical therapy planning	Tunez, Aguila, and Marin (2001)
Plant process control	Acosta, Gonzalez, and Pulido (2001)
Outage locating planning	Liu and Schulz (2002)
Concurrent system design	Mills and Gomaa (2002)
Case validation	Knauf, Gonzalez, and Abel (2002)
Chip design	Bourbakis, Mogzadeh, Mertoguno, and Koutsougeras (2002)
Agricultural planning	Cohen and Shoshany (2002)
Power transmission protection	Orduna, Garces, and Handschin (2003)
Crop production planning	Edrees, Rafea, Fathy, and Yahia (2003)
Tropospheric chemistry modeling	Saunders, Pascoe, Johnson, Pilling, and Jenkin (2003)
Urban design	Xirogiannis, Stefanou, and Glykas (2004)
Planar robots	Sen, Minambres, Garrido, Almansa, and Soto (2004)

4. Neural networks and their applications

An artificial neural network (ANN) is a model that emulates a biological neural network. This concept is used to implement software simulations for the massively parallel processes that involve processing elements interconnected in network architecture. The artificial neuron receives inputs that are analogous to the electrochemical impulses that the dendrites of biological neurons receive from other neurons. The output of the artificial neuron corresponds to signals sent out from a biological neuron over its axon. These artificial signals can be changed similarly to the physical changes occurring at neural synapses (Turban & Aronson, 2001).

Some of the applications that are implemented by neural networks are the following: fault diagnosis, optimal power flow, decision making, alarm processing system, inference mechanisms, diagnostic system, machine learning, power load forecasting, facility layout design, process control, knowledge learning, gold mining process design, robotic systems, parameter setting, waste treatment, engineering ceramics, mitigation processes control, acoustic signal diagnosing, crude oil distillation, and biomedical application. The methodology of neural networks and their applications are categorized in Table 3.

Table 3
Neural networks and their applications

Neural networks/applications	Authors
Fault diagnosis	Wang, Qu, Liu, and Cheng (2004), Yang, Han, and Kim, (2004)
Optimal power flow	
Decision making	
Alarm processing system	
Inference mechanisms	
Diagnostic system	
Machine learning	Fu (1998)
Power load forecasting	
Facility layout design	
Process control	
Knowledge learning	
Gold mining process design	
Robotic systems	
Parameter setting	
Waste treatment	
Biomedical application	
Mitigation processes control	
Engineering ceramics	
Acoustic signal diagnosing	Li, Tasi, Tasi, and Chiu (2004)
Crude oil distillation	Liau et al. (2004)

5. Fuzzy expert systems and their applications

Fuzzy ESs are developed using the method of fuzzy logic, which deals with uncertainty. This technique, which uses the mathematical theory of fuzzy sets, simulates the process of normal human reasoning by allowing the computer to behave less precisely and logically than conventional computers. This approach is used because decision-making is not always a matter of black and white, true or false; it often involves gray areas and the term *may be*. Accordingly, creative decision-making processes can be characterized unstructured, playful, contentious, and rambling (Jamshidi, Titli, Zadeh, & Boverie 1997).

Some applications implemented by fuzzy ESs are such as: power load forecasting, online scheduling, chemical

Table 4
Fuzzy expert systems and their applications

Fuzzy expert systems/ applications	Authors
Power load forecasting	Kim, Park, Hwang, and Kim (1995)
Online scheduling	Chang and Thia (1996)
Chemical process fault diagnosis	Ozyurt and Kandel (1996)
Ecological planning	Zhu, Band, Dutton, and Nimlos (1996)
Power system diagnosis	Cho and Park (1997)
Control systems	Bugarin and Barro (1998)
Uncertainly reasoning	Pan, DeSouza, and Kak (1998)
Knowledge integration	Lee, Han, Song, and Lee (1998)
Fault diagnosis	Lee et al. (2000) and Soliman, Rizzoni, and Kim (1999)
Power system classification	Dash, Mishra, Salama, and Liew (2000)
Fault detection	EI-Shal and Morris (2000)
Demand evaluation	Benson and Asgarpoor (2000)
Wastewater treatment	Carrasco, Rodriguez, Punal, Roca, and Lema (2004), Punal, Rodriguez, Carrasco, Roca, and Lema (2002), and Punal et al. (2001)
Machinability data selection	Wong and Hamouda (2002, 2003)
Water supply forecast	Mahabir, Hicks, and Fayek (2003)
Radiography classification	Liao (2003)
On-line analytic processing	Leung, Lau, and Kwong (2003)
Hotel selection	Ngai and Wat (2003)
Dryer tool integration	Lababidi and Baker (2003)
Medical diagnosis	Meesad and Yen (2003) and Sendelj and Devedzic (2004)
Pooled flood frequency analysis	Shu and Burn (2004)
Medical consultation system	Boegl, Adlassnig, Hayashi, Rothenfluh, and Leitich (2004)
Job matching	Drigs et al. (2004)
Performance indexing	Padilla-Medina and Sanchez-Marin (2004)
Computer security	Reznik and Dabke (2004)
Gesture recognition	Frantti and Kallio (2004)

process fault diagnosis, ecological planning, control systems, uncertainly reasoning, knowledge integration, fault diagnosis, power system classification, fault detection, demand evaluation, wastewater treatment, machinability data selection, water supply forecast, radiography classification, on-line analytic processing, hotel selection, dryer tool integration, pooled flood frequency analysis, medical consultation system, job matching, performance indexing, computer security, gesture recognition, and medical diagnosis. The methodology of fuzzy ESs together with their applications is categorized in Table 4.

6. Object-oriented methodology and their applications

Object-oriented methodology combines into one object data together with the specific procedures that operate on this data, where the object combines data and program code. Instead of passing data to procedures, programs send a message for an object to perform a procedure that is already embedded in it. Then, the same message may be sent to many different objects, but each will implement that message differently. An object's data are encapsulated from other parts of the system, so each object is an independent software building block that can be used in many different systems without changing the program code.

Some applications implemented by object-oriented methodology include the following: industry diagnosis, knowledge learning, manufacturing information network, power system maintenance, knowledge engineering, syntactic programming, and knowledge representation. The methodology of object-oriented methodology and their applications are categorized in Table 5.

Table 5
Object-oriented methodology and their applications

Object-oriented methodology/ applications	Authors
Industry diagnosis	Batanov and Cheng (1995)
Knowledge representation	Vranes and Stanojevic (1995)
Electronic power capacity planning	Deb (1995)
Knowledge learning	Menzies (1997)
Power system maintenance	Kawahara, Sasaki, Kubokawa, Asahara, and Sugiyama (1998)
Knowledge engineering	Geymayr and Ebecken (1998)
Manufacturing information network	Lau, Tso, and Ho (1998)
Syntactic programming	Depradine (2003)

7. Case-based reasoning and their applications

The basic idea of CBR is to adapt solutions that were used to solve previous problems and use them to solve new problems. In CBR, descriptions of past experience of human specialists, represented as cases, are stored in a database for later retrieval when the user encounters a new case with similar parameters. The system searches for stored cases with problem characteristics similar to the new one, finds the closest fit, and applies the solutions of the old case to the new case. Successful solutions are tagged to the new case and both are stored together with the other cases in the knowledge base. Unsuccessful solutions also are appended to the case base along with explanations as to why the solutions did not work (Kolonder, 1994).

Some of the applications implemented by CBR include the following: manufacturing process design, knowledge management, power system restoration training, ultrasonic inspection, medical planning, medical application, fault diagnosis, e-learning, and knowledge modeling. These CBR and their applications are categorized in Table 6.

8. Modeling and their applications

Modeling methodology becomes an interdisciplinary methodology of ES in order to build formal relationships with logical model design in different knowledge/problem

Table 6
Case-based reasoning and their applications

Case-based reasoning/applications	Authors
Manufacturing process design	Takahashi, Oono, and Saitog (1995)
Knowledge management	Noh, Lee, Kim, Lee, and Kim (2000)
Power system restoration training	Islam and Chowdhury (2001)
Ultrasonic inspection	Jarmulak, Kerckhoffs, and Veen (2001)
Medical planning	Abidi and Manickam (2002)
Medical application	Montani and Bellazzi (2002)
Knowledge modeling	Gardan and Gardan (2003)
Fault diagnosis	Yang et al. (2004)
E-learning	Fu and Shen (2004)

domains. Furthermore, modeling technology can provide quantitative methods to analyze data to represent or acquire expert knowledge with inductive logic programming or algorithms so that AI, cognitive science and other research fields could have broader platforms to implement technologies for ES development.

The applications implemented by modeling are such as: process control, medical analysis, management decision-making, software evaluation, medical system validation, assembly task planning and simulation, transport terminal design, project allocation, and endometrial hyperplasia classification. The methodology of modeling and their applications are categorized in Table 7.

9. System architecture and their applications

System architecture of an ES is similar to an architectural sketch of a house. It gives users a general idea of what the system will look like and how it is going to implement systems. The architecture shows the general capabilities of the system, the users' interfaces, system functions, system (data) flow, system management, DBMS, necessary protocol, and specific programming language, such as blackboard architecture, CommonKADS, etc. Once the system architecture design and implementation are completed, users can manipulate and control system functions on the system architecture.

Table 7
Modeling and their applications

Modeling/applications	Authors
Process control	
Medical analysis	Peng, Xiao, Nie, Wang, and Wang (1996)
Management decision-making	Mookerjee and Mannino (1997)
Software evaluation	Vlahavas, Stamelos, Refanidis, and Tsoukias (1999)
Medical system validation	Martin-Baramera et al. (2000)
Assembly task planning and simulation	Zha and Lim (2000)
Endometrial hyperplasia classification	Morrison et al. (2002)
Transport terminal design	Abacoumkin and Ballis (2004)
Project allocation	Cheung, Hong, and Ang (2004)

Table 8
System architecture and their applications

System architecture/applications	Authors
Material evaluation and selection	Mahmoud and AL-Hammad (1996)
Computer aided design	Tucho, Sierra, Fernandez, Vijande, and Moris (2003) and Vranes and Stanojevic (1999)
Ergonomics design	Gilad and Karni (1999)
ISO system implementation	Khan and Hafiz (1999)
Corporate recovery decision support	Collier, Leech, and Clark (1999)
Concurrent engineering	Reidsema and Szczerbicki (2001)
Military application	Liao (2001)
Training simulator	Lopez, Flores, and Garcia (2003)
Ferryboat configuration	Shaalan, Rizk, Abdelhamid, and Bahgat (2004)
Liquid retaining structure design	Chau and Albermani (2004)

Some of the applications implemented by system architecture illustrate the following: material evaluation and selection, computer aided design, ergonomics design, ISO system implementation, corporate recovery decision support, concurrent engineering, military application, training simulator, liquid retaining structure design, and ferryboat configuration. These System architectures and their applications are categorized in Table 8.

10. Intelligent agents and their applications

An IA is a computer program that helps a user with routine computer tasks. This is a new technology, and as such there are several definitions, database capabilities, and different applications in autonomous programs. Several of the names used to describe IAs are include software agents, wizards, and multi-agent (Turban & Aronson, 2001).

Some of the applications implemented by IAs are such as: tutoring systems, system analysis and design, electronic service maintenance, carbon contamination rules, knowledge representation, adaptive systems, air pollution control, building architecture design, agricultural decision support, industry simulation, and knowledge engineering on the WWW platform. The methodology of IAs together with their applications is categorized in Table 9.

11. Ontology and their applications

Ontology is a system of vocabulary, which is used as a fundamental concept for describing the task/domain knowledge to be identified. This vocabulary is used as a communication basis between domain experts and knowledge engineers. Accordingly, a reusable task/domain model can be represented and a computer program code is

Table 9
Intelligent agents and their applications

Intelligent agents/applications	Authors
Tutoring systems	Cruces and Arriaga (2000)
Supply chain	Gjerdrum, Shah, and Papageorgiou (2001)
System analysis and design	Gruer, Hilaire, Koukam, and Cetnarowicz (2002)
Electronic service maintenance	Yu, Iung, and Panetto (2003)
Carbon contamination rules	Vegh (2003)
Knowledge representation	Qian, Li, Jiang, and Wen (2003)
Industry simulation	Aldea et al. (2004)
Adaptive systems	Juuso (2004)
Air pollution control	Zhou, Huang, and Chan (2004)
Building architecture design	Alibaba and Ozdeniz (2004)
Olive oil automation	Bonstre et al. (2004)
Agricultural decision support	Thomson and Willoughby (2004)
Knowledge engineering on the WWW platform	Shaalan, EI-Badry, and Rafea (2004)

generated in that ontology for knowledge acquisition, reuse, heuristic learning.

Some applications implemented by ontology include the following: medical decision support, knowledge reuse, preventive control, landscape assessment, knowledge acquisition, and chess heuristic pruning. These ontology and their applications are categorized in Table 10.

12. Database methodology and their applications

A database is a collection of data organized to efficiently serve many applications by centralizing the data and minimizing redundant data (McFadden, Hoffer, & Prescott, 2000). A DBMS is the software that permits an organization to centralize data, manage them efficiently, and provide access to the stored data by application programs (Laudon & Laudon, 2002). However, some large databases make knowledge discovery computationally expensive because some domains or background knowledge, hidden in the database may guide and restrict the search for important knowledge. Therefore, modern database methodologies need to process large volumes, multiple hierarchies, and different data formats to discover in-depth expert knowledge from large databases, such as data mining and searching approach.

Table 10
Ontology and their applications

Ontology/applications	Authors
Medical decision support	Tu, Eriksson, Gennari, Shahar, and Musen (1995)
Knowledge reuse	Takaoka and Mizoguchi (1996)
Preventive control	Thukaram and Parthasarathy (1997)
Landscape assessment	Martinez-Bejar, Ibanez-Cruz, Compton, and Cao (2001)
Knowledge acquisition	Ruiz-Sanchez, Valencia-Garcia, Fernandez--Breis, Martinez-Bejar, and Compton (2003)
Chess heuristic pruning	Montani and Bellazzi (2002)
Knowledge modelling	Gardan and Gardan 2(003)

Table 11
Database methodology and their applications

Database methodology/applications	Authors
Power system planning	Park and Lee (1995)
Geography planning	Kirkby (1996)
Geographical information system	Filis, Sabrakos, Yialouris, Sideridis, and Mahaman (2003)
Sedimentary rock interpretation	Abel, Silva, Ros, Mastella, and Campbell (2004)
Traditional Chinese medicine diagnosis	Wang et al. (2004)
Medical expert system	Yan et al. (2004)

Some applications implemented by database methodology present as the following: power system planning, geography planning, geographical information system, sedimentary rock interpretation, traditional Chinese medicine diagnosis, and medical ES. The methodology of database methodology and their applications are categorized in Table 11.

13. Discussions, limitations, and suggestions

13.1. Discussions

ES methodologies and applications are a broad category of research issues on ES Some specific methodologies and methods are presented as examples for exploring the suggestions and solutions to specific ES problem domains. Therefore, methodologies and applications of ES are attracting much attention and efforts, both academic and practical. From this literature review, we can see that ES methodologies and applications developments are diversified due to their authors' backgrounds, expertise, and problem domains. This is why some authors can appear in the literature on different methodologies and applications.

On the other hand, some methodologies have common concepts, and types of methodology. For example, rule-based systems and knowledge-based systems, or fuzzy logic versus ANN methodology. However, a few authors work in different methodologies and applications. This indicates that the trend of development on methodology is also diversified due to author's research interests and abilities in the methodology and problem domain. This may indicate that the development of ES methodologies is directed toward expertise orientation.

Furthermore, some applications have a high degree of overlap in different methodologies. For example, teaching/ training, knowledge acquisition, knowledge representation, knowledge learning, fault diagnosis/detection, medical applications, production planning, system design/development, modeling, process control, decision making, waste treatment, resource management, biomedical application, robotic systems, forecasting, ecological planning, agriculture planning, geoscience, power system planning, chemical application, industry planning, management issues, and knowledge reuse, are all topics of different methodologies, which implement ES in a common problem domain. This indicates that those applications are the major trend of ES development, and many methodologies focus on these problems. This may direct development of ES applications toward problem domain orientation.

In this paper, most of the articles discussed were from different categories including agriculture, agronomy, automation, biochemistry, biology, chemistry, computer science, biology, ecology, education, energy, engineering, entomology, environmental sciences, genetics, geochemistry, geology, geosciences, health care sciences, hematology, hydrology, materials, mathematics, mechanics, medical, military, operation research/management sciences, ontology, plant science, remote sensing, robotics, and water resources, which retrieved from Elsevier SDOS, IEEE Xplore, EBSCO (electronic journal service), Ingenta, and Wiley InterScience online database. We do not conclude that ES methodologies and applications are not developed in other science fields. However, we would like to see more ES methodologies and applications of different research fields published in order to broaden our horizon of academic and practice works on ES.

13.2. Limitations

Firstly, a literature review for the broad category of ES methodologies and applications is a difficult task due to the extensive background knowledge needed for collecting, studying, and classifying these articles. Although limited in background knowledge, this paper makes a brief literature review of ES from 1995 to 2004 in order to explore how ES methodologies and applications have developed in this period. Indeed, the categorization of methodologies and their applications is based on the keyword index and article abstract in this research. Some other articles may have implemented similar ES methodologies in their applications without an ES index, so this paper might not find these reference sources. Therefore, the first limitation of this article is the author's limited knowledge in presenting an overall picture of this subject.

Secondly, although 166 articles from 78 academic journals (five online databases) cited in this paper, there are other academic journals listed in the science citation index (SCI) engineering index (EI), and the social science citation index (SSCI), as well as other academic journals/magazines, practical articles and reports are not included in this survey. These would have provided more complete information to explore the development of ES methodologies and applications.

Thirdly, non-English publications are not considered in this survey to determine the effects of different cultures on the development of ES methodologies and applications. We believe that ES methodologies and applications in addition to those discussed in this article have also been developed and published in other areas and languages.

13.3. Suggestions

(1) *Other social science methodologies*. In this article, the definition of ES methodology is not complete because other methodologies, such as social science methodologies, were not included in the survey. However, qualitative questionnaires and statistical methods are another research technology to solve problems in social studies. For example, cognitive science, psychology and human behavior are used to implement different methods for exploring specific human expert problem. Therefore, other social sciences methodologies may include ES methodology categories in future works.
(2) *Integration of methodologies*. ES is an interdisciplinary research topic. Thus, future ES developments need integration with different methodologies, and this integration of methodologies and cross-interdisciplinary research may offer more technologies to investigate ES problems.
(3) *Change is a source of future ES development.* The change due to social and technical reasons may either enable or inhibit ES methodologies and application development. This means that inertia, stemming from the use of routine problem solving procedures, stagnant knowledge sources, and following past experience or knowledge may impede changes in terms of learning and innovation for individuals and organizations. Therefore, to continue creating, sharing, learning, and storing knowledge on different methodologies and application domains may also become a source of ES development.

14. Conclusions

This paper is based on a literature review of ES methodologies and applications from 1995 to 2004 using a keyword index and article title search. We conclude that ES methodologies are tending to develop towards expertise orientation and that ES applications development is a problem-oriented domain. It is suggested that different social science methodologies, such as psychology, cognitive science, and human behavior could implement ES as another kind of methodology. Integration of qualitative, quantitative and scientific methods and integration of ES methodologies studies may broaden our horizon on this subject. Finally, the ability to continually change and obtain new understanding is the power of ES methodologies, and will be the ES application of future works.

References

Abacoumkin, C., & Ballis, A. (2004). Development of an expert system for the evaluation of conventional and innovative technologies in the intermodal transport area. *European Journal of Operational Research*, *152*, 410–419.

Abel, M., Silva, A. L., Ros, L. F., Mastella, L. S., & Campbell, J. A. (2004). PetroGrapher: managing petrographic data and knowledge using an intelligent database application. *Expert Systems with Applications*, *26*, 9–18.

Abidi, S. S. R., & Manickam, S. (2002). Leveraging XML-based electronic medical records to extract experiential clinical knowledge. *International Journal of Medical Informatics*, *68*, 187–203.

Acosta, G., Gonzalez, C. A., & Pulido, B. (2001). Basic tasks for knowledge-based supervision in process control. *Engineering Applications of Artificial Intelligence*, *14*, 441–455.

Afgan, N. H., & Carvalho, M. G. (1996). Knowledge-based expert system for fouling assessment of industrial heat exchangers. *Applied Thermal Engineering*, *16*, 203–208.

Aldea, A., Banares-Alcantara, R., Jimenez, L., Moreno, A., Martinez, J., & Riano, D. (2004). The scoipe of application of multi-agent systems in the process industry: three case studies. *Expert Systems with Applications*, *26*, 39–47.

Alibaba, H. Z., & Ozdeniz, M. B. (2004). A building elements selection system for architects. *Building and Environment*, *39*, 307–316.

Alonso, F., Fuertes, J. L., Martinez, L., & Montes, C. (2000). An incremental solution for developing knowledge-based software: its application to an expert system for isokinetics interpretation. *Expert Systems with Applications*, *18*, 165–184.

Alonso-Amo, F., Perez, A. G., Gomez, G. L., & Montes, C. (1995). An expert system for homeopathic glaucoma treatment (SEHO). *Expert Systems with Applications*, *8*, 89–99.

Baeza, J. A., Ferreira, E. C., & Laufuente, J. (2000). Knowledge-based supervision and control of wastewater treatment plant: a real-time implementation. *Water Science and Technology*, *41*, 129–137.

Barrera-Cortes, J., Astruc, J. P., & Tufeu, R. (2001). Knowledge base specification to automate the fluid critical point of fluids. *Applied Artificial Intelligence*, *15*, 453–470.

Batanov, D. N., & Cheng, Z. (1995). An object-oriented expert system for fault diagnosis in the ethylene distillation process. *Computers in Industry*, *27*, 237–249.

Benson, S. J., & Asgarpoor, S. (2000). A fuzzy expert system for evaluation of demand-side management alternatives. *Electronic Machines and Power Systems*, *28*, 749–760.

Boegl, K., Adlassnig, K. P., Hayashi, Y., Rothenfluh, T. E., & Leitich, H. (2004). Knowledge acquisition in the fuzzy knowledge representation framework of a medical consultation system. *Artificial Intelligence in Medicine*, *30*, 1–26.

Bonstre, A., Ors, R., & Peris, M. (2004). Advanced automation of a flow injection analysis system for quality control of olive oil through the use of a distributed expert system. *Analytica Chimica Acta*, *506*, 189–195.

Bourbakis, N. G., Mogzadeh, a., Mertoguno, S., & Koutsougeras, C. A. (2002). A knowledge-based expert system for automatic visual VLSI reverse-engineering: VLSI layout version. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, *32*, 428–437.

Bugarin, A. J., & Barro, S. (1998). Reasoning with truth values on compacted fuzzy chained rules. *IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics*, *28*, 34–46.

Carrasco, E. F., Rodriguez, J., Punal, A., Roca, E., & Lema, J. M. (2004). Diagnosis of acidification states in an anaerobic wastewater yreatment plant using a fuzzy-based system. *Control Engineering Practice*, *12*, 59–64.

Chan, Y. F., Ma, H. K., Chan, H. Y., & Chen, T. Y. (1995). Teaching family planning with expert system. *Computers Education*, *24*, 293–298.

Chang, C. S. M., & Thia, B. S. (1996). Online rescheduling of mass rapid transit systems: fuzzy expert system approach. *IEE Proceedings Electronic Power Applications*, *143*, 307–316.

Chau, K. W., & Albermani, F. (2004). Hybrid knowledge representation in a blackboard KBS for liquid retaining structure design. *Engineering Application of artificial Intelligence*, *17*, 11–18.

Cheung, Y., Hong, G. M., & Ang, K. K. (2004). A dynamic project allocation algorithm for a distributed expert system. *Expert Systems with Applications*, *26*, 225–232.

Cho, H. J., & Park, J. K. (1997). An expert system for fault section diagnosis of power systems using fuzzy relations. *IEEE Transactions on Power Systems*, *12*, 342–348.

Clark, M. C., Hall, L. O., Goldgof, D. B., Velthuizen, R., Murtagh, R., & Silbiger, M. S. (1998). Automatic tumor segmentation using knowledge-based techniques. *IEEE Transactions on Medical imaging*, *17*, 187–201.

Cohen, Y., & Shoshany, M. (2002). A national knowledge-based crop recognition in Mediterranean environment. *International Journal of Applied Earth Observation*, *4*, 75–87.

Collier, P. A., Leech, S. A., & Clark, N. (1999). A validated expert system for decision making in corporate recovery. *International Journal of Intelligent System in Accounting, Finance and Management*, *8*, 75–88.

Croce, F., Delfino, B., Fazzini, P. A., Massucco, S., Morini, A., Silvestro, F., & Sivieri, M. (2001). Operation and management of the electronic system for industrial plants: an expert system prototype for load-scheduling operator assistance. *IEEE Transactions on Industry Applications*, *37*, 701–708.

Cruces, A. L. L., & Arriaga, F. D. (2000). Reactive agent design for intelligent tutoring systems. *Cybernetics and Systems: An International Journal*, *31*, 1–47.

Dash, P. K., Mishra, S., Salama, M. M., & Liew, A. C. (2000). Classification of power system disturbances using a fuzzy expert system and a fourier linear combiner. *IEEE Transactions on power Delivery*, *15*, 472–477.

Dawood, N. N. (1996). A strategy of knowledge elicitation for developing an integrated bidding/production management expert system for the precast industry. *Advances in Engineering Software*, *25*, 225–234.

Deb, A. K. (1995). Object-oriented expert system estimated line ampacity. *IEEE Computer Application in Power*, *12*, 30–35.

Depradine, C. (2003). Expert system for extracting syntactic information from Java code. *Expert Systems with Applications*, *25*, 187–198.

Deshmukh, A., & Talluru, L. (1998). A rule-based fuzzy reasoning system for assessing the risk of management fraud. *International Journal of Intelligent Systems in Accounting, Finance and Management*, *7*, 223–241.

Dhaliwal, J. S., & Benbasat, I. (1996). The use and effects of knowledge-based system explanations: theoretical foundations and a framework for empirical evaluation. *Information Systems Research*, *7*, 342–362.

Dirks, S., Kingston, J. K. C., & Haggith, M. (1995). Development of a KBS for personal financial planning guided by pragmatic KADS. *Expert Systems with Applications*, *9*, 91–101.

Drigs, A., Kouremenos, S., Vrettos, S., & Kouremenos, D. (2004). An expert system for job matching of the unemployed. *Expert Systems with Applications*, *26*, 217–224.

Duan, Y., Edwards, J. S., & Robins, P. C. (1998). Experiences with EXGAME: an expert system for playing a competitive business game. *International Journal of Intelligent System in Accounting, Finance, and Management*, *7*, 1–19.

Dutta, S. (1997). Strategies for implementing knowledge-based systems. *IEEE Transactions on Engineering Management*, *44*, 79–90.

Edrees, S. A., Rafea, A., Fathy, I., & Yahia, M. (2003). NEPER: a multiple strategy wheat expert system. *Computers and Electronics in Agriculture*, *40*, 27–43.

EI-Shal, S. M., & Morris, A. S. (2000). A fuzzy system for fault detection in statistical process control of industrial processes. *IEEE Transactions on Systems, Man, and Cybernetics—Part C: Applications and Reviews*, *30*, 281–292.

Fezzani, D., Piquet, H., & Foch, H. (1997). Expert system for the CAD in power electronics—application to UPS. *IEEE Transaction on Power Electronics*, *12*, 578–586.

Filis, I. V., Sabrakos, M., Yialouris, C. P., Sideridis, A. B., & Mahaman, B. (2003). GEDAS: an integrated geographical expert database system. *Expert Systems with Applications*, *24*, 25–34.

Finch, D. J., & Lees, P. F. (1997). A hybrid knowledge-based system for chemical incident management. *Expert Systems with Applications*, *12*, 349–361.

Frantti, T., & Kallio, S. (2004). Expert system for gesture recognition in terminal's user interface. *Expert Systems with Applications*, *26*, 189–202.

Fu, Y., & Shen, R. (2004). GA based CBR approach in Q&A system. *Expert Systems with Applications*, *26*, 167–170.

Gardan, N., & Gardan, Y. (2003). An application of knowledge based modeling using scripts. *Expert systems with Applications*, *25*, 555–568.

Gilad, I., & Karni, R. (1999). Architecture of an expert system for ergonomics analysis and design. *International Journal of Industrial Ergonomics*, *23*, 205–221.

Girard, N., & Hubert, B. (1999). Modeling expert knowledge with knowledge-based systems to design decision aids. *Agricultural Systems*, *59*, 123–144.

Gjerdrum, J., Shah, N., & Papageorgiou, L. G. (2001). A combined optimization and agent-based approach to supply chain modeling and performance assessment. *Production Planning and Control*, *12*, 81–88.

Goethe, J. W., & Bronzino, J. D. (1995). An expert system for monitoring psychiatric treatment. *IEEE Engineering in Medicine and Biology*, *November/December*, 776–780.

Gomolka, Z., & Orlowski, C. (2000). Knowledge management in creating hybrid systems for environmental protection. *Cybernetics and Systems: An International Journal*, *31*, 507–529.

Graham-Jones, P. J., & Mwllor, B. G. (1995). Expert and knowledge-based systems in failure analysis. *Expert Systems with Applications*, *2*, 137–149.

Gruer, P., Hilaire, V., Koukam, A., & Cetnarowicz, K. (2002). A formal framework for multi-agent systems analysis and design. *Expert Systems with Applications*, *23*, 349–355.

Guerreiro, M. A., Andrietta, S. R., & Maugeri, F. (1997). Expert system for the design of an industrial fermentation plant for the production of alcohol. *Journal of Chemical Technological Biotechnology*, *68*, 163–170.

Hamada, K., Baba, T., Sato, K., & Yufu, M. (1995). Hybridizing a genetic algorithm with rule-based reasoning for production planning. *IEEE Expert*, *35*, 60–67.

Hatzilygeroudis, J., & Prentzas, J. (2004a). Integrating (rules, neural networks) and cases for knowledge representation and reasoning in expert systems. *Expert Systems with Applications*, *27*, 63–75.

Hatzilygeroudis, J., & Prentzas, J. (2004b). Using a hybrid rule-based approach in developing an intelligent tutoring system with knowledge acquisition and update capabilities. *Expert Systems with Applications*, *26*, 477–492.

Higa, K., & Lee, H. G. (1998). A graph-based approach for rule integrity and maintainability in expert system maintenance. *Information and Management*, *33*, 273–285.

Ilgun, K., Kemmerer, R. A., & Porras, P. A. (1995). State transition analysis: a rule-based intrusion detection approach. *IEEE Transactions on Software Engineering*, *21*, 181–199.

Islam, S., & Chowdhury, N. (2001). A case-based Windows graphic package for the education and training of power system restoration. *IEEE Transaction on Power Systems*, *16*, 181–192.

Jamshidi, M. A., Titli, A., Zadeh, L., & Boverie, S. (1997). *Applications of fuzzy logic: Towards high machine intelligent quotient systems*. Upper Saddle River, NJ: Prentice Hall.

Jarmulak, J., Kerckhoffs, E. J. H., & Veen, P. P. (2001). Case-based reasoning for interpretation of data from non-destructive testing. *Engineering Applications of Artificial Intelligence*, *14*, 401–417.

Juuso, E. K. (2004). Integration of intelligent systems in development of smart adaptive systems. *International Journal of Approximate reasoning*, *35*, 307–337.

Kawahara, K., Sasaki, H., Kubokawa, J., Asahara, H., & Sugiyama, K. (1998). A proposal of a supporting expert system for outage planning of electronic power facilities retaining high power supply reliability. *IEEE Transactions on Power Systems*, *13*, 1453–1462.

Keefe, R. M., & Preece, A. D. (1996). The development, validation and implementation of knowledge-based systems. *European Journal of Operational Research*, *92*, 458–473.

Khan, M. K., & Hafiz, N. (1999). Development of an expert system for implementation of ISO quality systems. *Total Quality Management*, *10*, 47–59.

Kim, H. S., & Im, Y. T. (1999). An expert system for cold forging process design based on a depth-first search. *Journal of Materials Processing Technology*, *95*, 262–274.

Kim, K. H., Park, J. K., Hwang, K. J., & Kim, S. H. (1995). Implementation of hybrid short-term load forecasting system using artificial neural networks and fuzzy expert systems. *IEEE Transactions on Power Systems*, *10*, 1534–1539.

Kirkby, S. D. (1996). Integrating a GIS with an expert system to identify and manage dryland salinization. *Applied Geography*, *16*, 289–302.

Knauf, R., Gonzalez, A. J., & Abel, T. (2002). A framework for validation of rule-based systems. *IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics*, *32*, 281–291.

Kolonder, J. L. (1994). *Case-based reasoning*. New York: Morgan Kaufmann.

Lababidi, H., & Baker, C. G. J. (2003). Web-based expert system for food dryer selection. *Computers and Chemical Engineering*, *27*, 997–1009.

Lau, H. C., Tso, S. K., & Ho, J. K. L. (1998). Development of an intelligent task management system in a manufacturing information network. *Expert Systems with Applications*, *15*, 165–179.

Laudon, K. C., & Laudon, J. P. (2002). *Essential of management information systems* (5th ed). Englewood cliffs, NJ: Prentice Hall.

Lee, H. J., Park, D. Y., Ahn, B. S., Park, Y. M., Park, J. K., & Venkata, S. S. (2000). A Fuzzy expert system for the integrated fault diagnosis. *IEEE Transactions on Power Delivery*, *15*, 833–845.

Lee, K. C., Han, J. H., Song, Y. U., & Lee, W. J. (1998). A fuzzy logic-driven multiple knowledge integration framework for improving the performance of expert systems. *International Journal of Intelligent System in Accounting, Finance, and Management*, *7*, 213–222.

Leon, C., Mejias, M., Luque, J., & Gonzalo, F. (1999). Expert system for the integrated management of a power utility's communication system. *IEEE Transactions on Power Delivery*, *14*, 1208–1212.

Leung, D., & Romagnoli, J. (2000). Dynamic probabilistic model-based expert system for fault diagnosis. *Computers and Chemical Engineering*, *24*, 2473–2492. *Expert Systems with Applications*, 25 313–330.

Leung, R. W. K., Lau, H. C. W., & Kwong, C. K. (2003). An expert system to support the optimization of ion plating process: an OLAP-based fuzzy-cum-GA approach.

Li, W., Tasi, Y. P., Tasi, & Chiu, C. L. (2004). The experimental study of the expert system for diagnosing unbalance by ANN and acoustic signals. *Journal of Sound and Vibration*, *272*, 69–83.

Liao, S. H. (2001). A knowledge-based architecture for implementing military geographical intelligence system on Intranet. *Expert Systems with Applications*, *20*, 313–324.

Liao, T. W. (2003). Classification of welding flaw types with fuzzy expert systems. *Expert Systems with Applications*, *25*, 101–111.

Liau, L. C. K., Yang, C. K., & Tasi, M. T. (2004). Expert system of a crude oil distillation unit for process optimization using neural networks. *Expert Systems with Applications*, *26*, 247–255.

Lienqueo, M. E., Salgado, J. C., & Asenjo, J. A. (1999). An expert system for selection of protein purification process: experimental validation. *Journal of Chemical Technology and Biotechnology*, *74*, 293–299.

Liu, Y., & Schulz, N. N. (2002). Knowledge-based system for distribution system outage locating using comprehensive information. *IEEE Transactions on Power Systems*, *17*, 451–456.

Lopez, M. A. A., Flores, C. H., & Garcia, E. G. (2003). An intelligent tutoring system for turbine startup training of electrical power plant operators. *Expert Systems with Applications*, *24*, 95–101.

Lu, X., & Simmonds, S. H. (1997). KBES for evaluating R.C. framed buildings using fuzzy sets. *Automation in Construction*, *6*, 121–137.

Mahabir, C., Hicks, F. E., & Fayek, A. R. (2003). Application of fuzzy logic to forecast seasonal runoff. *Hydrological Processes*, *17*, 3749–3762.

Mahaman, B. D., Harizanis, P., Filis, I., Antonopoulou, E., Yialouris, C. P., & Sideridis, A. B. (2002). A diagnostic expert system for honeybee pests. *Computers and Electronics in Agriculture*, *36*, 17–31.

Mahaman, B. D., Passam, H. C., Sideridis, A. B., & Yialouris, C. P. (2003). DIARES-IPM: a diagnostic advisory rule-based expert system for integrated pest management in Solanaceous crop systems. *Agricultural Systems*, *76*, 1119–1135.

Mahmoud, M. A. A., & AL-Hammad, A. (1996). An expert system for evaluating and selection of floor finishing materials. *Expert Systems with Applications*, *10*, 281–303.

Manohar, P. A., Shivathaya, S. S., & Ferry, M. (1999). Design of an expert system for the optimization of steel compositions and process route. *Expert Systems with Applications*, *17*, 129–134.

Marchevsky, A. M., Truong, H., & Tolmachoff, T. (1997). A rule-based expert system for the automatic classification of DNA 'ploidy' histograms measured by the CAS 200 image analysis system. *Cytometry*, *30*, 39–46.

Martin-Baramera, M., Sancho, J. J., & Sanz, F. (2000). Controlling for change agreement in the validation of medical expert systems with no gold standard: PNEUMON-IA and PENOIR revisited. *Computers and Biomedical Research*, *33*, 380–397.

Martinez-Bejar, R., Ibanez-Cruz, F., Compton, P., & Cao, T. M. (2001). An easy-maintenance, reusable approach for building knowledge-based systems: application to landscape assessment. *Expert Systems with Applications*, *20*, 153–162.

Matsatsinis, N. F., Doumpos, M., & Zopounidis, C. (1997). Knowledge acquisition and representation for expert systems in the field of financial analysis. *Expert Systems with Applications*, *12*, 247–262.

McCoy, M. S., & Levary, R. R. (2000). A rule-based pilot performance model. *International Journal of System Science*, *31*, 713–729.

McFadden, F. R., Hoffer, J. A., & Prescott, M. B. (2000). *Modern database management* (5th ed). New York: Prentice-Hall.

Meesad, P., & Yen, G. G. (2003). Combined numerical linguistic knowledge representation and its application to medical diagnosis. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, *33*, 206–222.

Menzies, T. (1997). Object-oriented patterns: lessons from expert systems. *Software Practice and Experience*, *27*, 1457–1478.

Mills, K., & Gomaa, H. (2002). Knowledge-based automation of a design method for concurrent systems. *IEEE Transactions on Software Engineering*, *28*, 228–255.

Mitra, R. S., & Basu, A. (1997). Knowledge representation in MICKEY: An expert system for designing microprocessor-based systems. *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, *27*, 467–479.

Mockler, R. J., Dologite, D. G., & Gartenfeld, M. E. (2000). Talk with the experts: learning management decision-making using CAI. *Cybernetics and Systems: An International Journal*, *31*, 431–464.

Montani, S., & Bellazzi, R. (2002). Supporting decisions in medical applications: the knowledge management perspective. *International Journal of Medical Informatics*, *68*, 79–90.

Mookerjee, V. S., & Mannino, M. V. (1997). Sequential decision models for expert system optimization. *IEEE Transactions on Knowledge and Data Engineering*, *9*, 675–687.

Morrison, M. L., McCliggage, W. G., Price, G. J., Diamond, J., Sheeran, M. R. M., & Mulholland, K. M. (2002). Expert system support using a Bayesian belief network for the classification of endometrial hyperplasia. *Journal of Pathology*, *197*, 403–414.

Mulvaney, D., & Bristow, C. (1997). A rule-based extension to the C++ language. *Software Practice and Experience*, *27*, 747–761.

Ngai, E. W. T., & Wat, F. K. T. (2003). Design and development of a fuzzy expert system for hotel selection. *Omega* , 275–286.

Noh, J. B., Lee, K. C., Kim, J. K., Lee, J. K., & Kim, S. H. (2000). A case-based reasoning approach to cognitive map-driven tacit knowledge management. *Expert Systems with Applications*, *19*, 249–259.

Orduna, E., Garces, F., & Handschin, E. (2003). Algorithmic-knowledge-based adaptive coordination in transmission protection. *IEEE Transactions on Power Delivery*, *18*, 61–70.

Ozyurt, B., & Kandel, A. (1996). A hybrid hierarchical neural network-fuzzy expert system approach to chemical process fault diagnosis. *Fuzzy Sets and Systems*, *83*, 11–25.

Padilla-Medina, J. A., & Sanchez-Marin, J. S. (2004). An adaptive fuzzy expert system to evaluate human visual performance. *Fuzzy Sets and Systems*, *142*, 321–334.

Pan, J., DeSouza, G. N., & Kak, A. C. (1998). FuzzyShell: a large-scale expert system shell using fuzzy logic for uncertainty reasoning. *IEEE Transactions on Fuzzy Systems*, *6*, 563–581.

Park, Y. M., & Lee, K. H. (1995). Application of expert system to power system restoration in local control center. *Electrical Power and Energy Systems*, *17*, 407–415.

Peng, C., Xiao, S., Nie, Z., Wang, Z., & Wang, F. (1996). Applying Bayes' theorem in medical expert systems. *IEEE Engineering in Medicine and Biology*, *May/June*, 76–79.

Plant, R. E., & Vayssieres, M. P. (2000). Combining expert system and GIS technology to implement a state-transition model of oak woodlands. *Computers and Electronics in Agriculture*, *27*, 71–93.

Punal, A., Rodriguez, J., Carrasco, E. F., Roca, E., & Lema, J. M. (2002). Expert system for the on-line diagnosis of anaerobic wastewater treatment. *Water Science and Technology*, *45*, 195–200.

Punal, A., Rodriguez, J., Franco, A., Carrasco, E. F., Roca, E., & Lema, J. M. (2001). Advanced monitoring and control of anaerobic wastewater treatment plants: diagnosis and supervision by a fuzzy-based expert system. *Water Science and Technology*, *43*, 191–198.

Qian, Y., Li, X., Jiang, Y., & Wen, Y. (2003). An expert system for real-time fault diagnosis of complex chemical processes. *Expert Systems with Applications*, *24*, 425–432.

Rahman, S., & Hazim, O. (1996). Load forecasting for multiple sites: development of an expert system-based technique. *Electronic Power Systems Research*, *39*, 161–169.

Ramaswamy, M., Sarkar, S., & Chen, Y. S. (1997). Using directed hypergraphs to verify rule-based expert systems. *IEEE Transactions on Knowledge and Data Engineering*, *9*, 221–237.

Reidsema, C., & Szczerbicki, E. (2001). A blackboard database model of the design planning process in concurrent engineering. *Cybernetics and Systems: An International Journal*, *32*, 755–774.

Reznik, L., & Dabke, K. P. (2004). Measurement models: application of intelligent methods. *Measurement*, *35*, 47–58.

Rodionov, S. N., & Martin, J. H. (1999). An expert system-based approach to prediction of year-to-year climatic variations in the north Atlantic region. *International Journal of Climatology*, *19*, 951–974.

Ruiz-Sanchez, J., Valencia-Garcia, R., Fernandez-Breis, T., Martinez-Bejar, R., & Compton, P. (2003). An approach for incremental knowledge acquisition from text. *Expert Systems with Applications*, *25*, 77–86.

Sabourin, L., & Villeneuve, F. (1996). OMEGA, an expert CAPP system. *Advances in Engineering Software*, *25*, 51–59.

Saunders, S. M., Pascoe, S., Johnson, A. P., Pilling, M. J., & Jenkin, M. E. (2003). Development and preliminary test results of expert system for the automatic generation of tropospheric VOC degradation mechanisms. *Atmospheric Environment*, *37*, 1723–1735.

Sen, M. D. L., Minambres, J. J., Garrido, A. J., Almansa, A., & Soto, J. C. (2004). Basic theoretical results for expert systems, application to the supervision of adaptation transients in planar robots. *Artificial intelligence*, *152*, 173–211.

Sendelj, R., & Devedzic, V. (2004). Fuzzy systems based on component software. *Fuzzy Sets and Systems*, *141*, 487–504.

Shaalan, K., EI-Badry, M., & Rafea, A. (2004a). A multiagent approach for diagnostic expert systems via the internet. *Expert Systems with Applications*, *27*, 1–10.

Shaalan, K., Rizk, M., Abdelhamid, Y., & Bahgat, R. (2004b). An expert system for the best weight distribution on ferryboats. *Expert Systems with Applications*, *26*, 397–411.

Shu, C., & Burn, D. H. (2004). Homogeneous pooling group delineation for flood frequency analysis using a fuzzy expert system with genetic enhancement. *Journal of Hydrology*, *291*, 132–149.

Soh, L. K., Tsatsoulis, C., Gineris, D., & Bertoia, C. (2004). ARKTOS: An intelligent system for SAR sea ice image classification. *IEEE Transactions on Geoscience and Remote Sensing*, *42*, 229–248.

Soliman, A., Rizzoni, G., & Kim, Y. W. (1999). Diagnosis of an automotive emission control system using fuzzy inference. *Control Engineering Practice*, *7*, 209–216.

Takahashi, M., Oono, J. I., & Saitog, K. (1995). Manufacturing process design by CBR with knowledge ware. *IEEE Expert*, *December*, 74–80.

Takaoka, Y., & Mizoguchi, R. (1996). Identification of ontologies to reuse knowledge for substation fault recovery support system. *Decision Support Systems*, *18*, 3–21.

Thomson, A. J., & Willoughby, I. (2004). A web-based expert system for advising on herbicide use in Great Britain. *Computers and Electronic in Agriculture*, *42*, 43–49.

Thukaram, B. D., & Parthasarathy, K. (1997). An expert system for power system voltage stability improvement. *Electrical Power and Energy Systems*, *19*, 385–392.

Tu, S. W., Eriksson, H., Gennari, H., Shahar, Y., & Musen, M. A. (1995). Ontology-based configuration of problem-solving methods and generation of knowledge-acquisition tools: application of PROTÉGÉ-II to protocol-based decision support. *Artificial Intelligence in Medicine*, *7*, 257–289.

Tucho, R., Sierra, J. M., Fernandez, J. E., Vijande, R., & Moris, G. (2003). Expert tutoring system for teaching mechanical engineering. *Expert Systems with Applications*, *24*, 415–424.

Tunez, S., Aguila, I. M., & Marin, R. (2001). An expertise model for therapy planning using abductive reasoning. *Cybernetics and Systems: An International Journal*, *32*, 829–849.

Turban, E., & Aronson, J. E. (2001). *Decision support systems and intelligent systems, sixth Edition* (6th ed). Hong Kong: Prentice International Hall.

Valenzuela, L. M., Bentley, J. M., & Lorenz, R. D. (2004). Expert system for integrated control and supervision of dry-end sections of paper machines. *IEEE Transactions on Industry Applications*, *40*, 680–691.

Vegh, J. (2003). The 'carbon aontamination' rule set implemented in an 'embedded expert system'. *Journal of Electron Spectroscopy and Related Phenomena*, *133*, 87–101.

Vlahavas, I., Stamelos, I., Refanidis, I., & Tsoukias, A. (1999). ESSE: an expert system for software evaluation. *Knowledge-Based Systems*, *12*, 183–197.

Volberda, H. W., & Rutges, A. (1999). FARSYS: a knowledge-based system for managing strategic change. *Decision Support Systems*, *26*, 99–123.

Vranes, S., & Stanojevic, M. (1995). Integrated multiple paradigms within the blackboard framework. *IEEE Transactions on Software Engineering*, *21*, 244–262.

Vranes, S., & Stanojevic, M. (1999). Design knowledge representation in Prolog/Rex. *Engineering Applications of Artificial Intelligence*, *12*, 221–228.

Wang, X., Qu, H., Liu, P., & Cheng, Y. (2004). A self-learning expert system for diagnosis in traditional Chinese medicine. *Expert Systems with Applications*, *26*, 557–566.

Wasiewicz, P., Janczak, T., Mulawka, J. J., & Plucienniczak, A. (2000). The inference based on molecular computing. *Cybernetics and Systems: An International Journal*, *31*, 283–315.

Wei, M. S., & Weber, F. (1996). An expert system for waste management. *Journal of Environmental Management*, *46*, 345–358.

Wiig, K. M. (1994). *Knowledge management, the central management focus for intelligent-acting organization*. Arlington: Schema Press.

Wong, S. V., & Hamouda, A. M. S. (2002). A fuzzy logic based expert system for machinability data-on-demand on the Internet. *Journal of Materials Processing Technology*, *124*, 57–66.

Wong, S. V., & Hamouda, A. M. S. (2003). The development of an online knowledge-based expert system for machinability data selection. *Knowledge-based Systems*, *16*, 215–229.

Wu, T. P., & Chen, S. M. (1999). A new method for constructing membership functions and fuzzy rules from training examples. *IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics*, *29*, 25–37.

Wu, C. H., & Lee, S. J. (1997). Enhanced high-level Petri nets with multiple colors for knowledge verification/validation of rule-based expert systems. *IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics*, *27*, 760–773.

Xirogiannis, G., Stefanou, J., & Glykas, M. (2004). A fuzzy cognitive map approach to support urban design. *Expert Systems with Applications*, *26*, 257–268.

Yan, H., Jiang, Y., Zheng, J., Fu, B., Xiao, S., & Peng, C. (2004). The internet-based knowledge acquisition and management method to construct large-scale distributed medical expert system. *Computer Methods and Programs in Biomedicine*, *74*, 1–10.

Yang, B. S., Han, T., & Kim, Y. S. (2004). Integration of ART-Kohoene neural network and case-based reasoning for intelligent fault diagnosis

Yu, R., Iung, B., & Panetto, H. (2003). A multi-agents based E-maintenance system with case-based reasoning decision support. *Engineering Applications of artificial Intelligence*, *16*, 321–333. *Expert Systems with Applications*, 26, 387–395.

Zha, X., & Lim, S. Y. E. (2000). Assembly/disassembly task planning and simulation using expert Petri nets. *International Journal of Production Research*, *15*, 3639–3676.

Zhou, Q., Huang, G. H., & Chan, C. W. (2004). Development of an intelligent decision support system for air pollution control at coal-fired power plants. *Expert Systems with Applications*, *26*, 335–356.

Zhu, A. X., Band, L. E., Dutton, B., & Nimlos, T. J. (1996). Automated soil inference under fuzzy logic. *Ecological Modeling*, *90*, 123–145.

Zupan, B., & Cheng, M. K. (1998). Optimization of rule-based systems using state space graphs. *IEEE Transactions on Knowledge and Data Engineering*, *10*, 238–254.