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.

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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 advice 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
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 infer 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, diagnosis.

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, diagnosis. 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, diagnosis. 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, diagnosis.

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 (Dhaliliwal & 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 1.

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<th>Table 1</th>
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<td>Production planning</td>
<td>Hamada, Baba, Sato, and Yufa (1995)</td>
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<td>Advisory system</td>
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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, gold mining process design, robotic systems, parameter setting, waste treatment, biomedical application, 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.

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...
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.

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.
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.

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

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**Table 7**

<table>
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<tr>
<th>Modeling/applications</th>
<th>Authors</th>
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<tbody>
<tr>
<td>Medical analysis</td>
<td>Mookerjee and Mannino (1997)</td>
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<td>Software evaluation</td>
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<tr>
<td>Medical system validation</td>
<td>Martin-Baramera et al. (2000)</td>
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<tr>
<td>Assembly task planning and simulation</td>
<td>Zha and Lim (2000)</td>
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<td>Endometrial hyperplasia classification</td>
<td>Morrison et al. (2002)</td>
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<td>Transport terminal design</td>
<td>Abacoumin and Ballis (2004)</td>
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<td>Project allocation</td>
<td>Cheung, Hong, and Ang (2004)</td>
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**Table 8**

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

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, geochisistry, 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


