

Fuzzy Expert Systems (FES) for Medical Diagnosis

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ABSTRACT

Fuzzy logic has proved to be the remarkable tool for building intelligent decision making systems based on the expert's knowledge and observations. This paper reviews the trend in development of FES and application potential over past two and half decades in the medical field, based on the references of 173 articles from 124 journals, several proceedings and web media. In order to investigate the significance of FES for medical diagnosis, the articles are classified into five distinct categories: Reviews and Surveys on Fuzzy Expert Systems in Medical Diagnosis, Applications of Fuzzy Expert Systems in Medical Diagnosis, Methodologies and Modelling of Fuzzy Expert Systems, Neuro-Fuzzy Approaches, Fuzzy Expert System Shells and Frameworks. The development of disease specific applications using FES is observed to be the area of most significant interest of the researchers. The earlier contributions are reviewed, classified, analyzed and suggested the future scope.

Keywords

Fuzzy expert systems, Medical diagnosis, Neuro-fuzzy systems, Fuzzy shells, Fuzzy frameworks

1. INTRODUCTION

Medical practitioners exhibit variation in decision making because of their approaches to deal with uncertainties and vagueness in the knowledge and information. The diagnostic decisions also depend upon experience, expertise and perception of the practitioner. As the complexity of system increases, it is not easy to follow a particular path of diagnosis without any mistake. Fuzzy logic presents powerful reasoning methods that can handle uncertainties and vagueness. The Fuzzy Expert Systems (FES) define imprecise knowledge and offers linguistic concept with excellent approximation to medical texts.¹ Fuzzy logic is a method to render precise what is imprecise in the world of medicine. FES play an important role in medicine for symptomatic diagnostic remedies. The technocrats identified potential and possible areas for implementation of FES for medical diagnosis. Also, the efforts have been made by various researchers to establish a roadmap to forecast the future developments of expert systems in medical diagnosis. The literature published upon FES in medical diagnosis encompasses a wide spectrum including reviews, applications, innovations, conceptual studies and development of diagnostic tools. The communications between medical scientists and computer engineers have lead to an interdisciplinary advance in the development of intelligent supporting tools and systems.² The expert systems are reported for the patient monitoring, prediction of conditions, handling of fuzzy queries in medical applications as well as evaluation and comparison of the

performances with existing practices. The scope for FES has found its applications in diagnosis, differential diagnosis, therapy, image analysis, pattern recognition, patient monitoring, medical data analysis, data bank, text analysis and of theory: multi-valued logic, fuzzy relations, fuzzy set theory, fuzzy classification, etc. Past studies are contributed to the development of diagnostic techniques, quantification of medical expertise, knowledge technology transfer, identification of usage patterns and applications of FES and their adoption in practice by the medical practitioners. This paper reviews a trend in the development of FES and applications over past two decades in the medical field, on the basis of the references of 173 technical papers contributed by various researchers in 124 journals, various proceedings and web media. The articles are classified into five distinct categories: Reviews and Surveys on Fuzzy Expert Systems in Medical Diagnosis, Applications of Fuzzy Expert Systems in Medical Diagnosis, Methodologies and Modelling of Fuzzy Expert Systems, Neuro-Fuzzy Approaches, Fuzzy Expert System Shells and Frameworks. Fig.1 represents the distribution of referred reference resources.

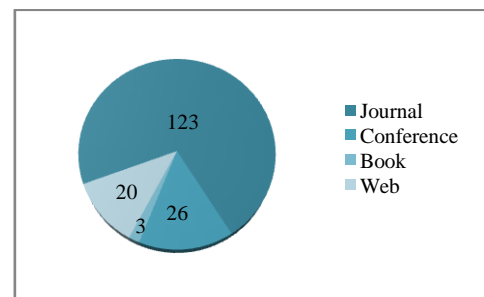


Fig 1: Distribution of reference resources

2. REVIEWS AND SURVEYS ON FUZZY EXPERT SYSTEMS IN MEDICAL DIAGNOSIS

The literature published by various authors under "Reviews and surveys on fuzzy expert systems in medical diagnosis" category found to be focused on the facets and modalities of experts systems pertaining to medical field. The potential and feasible areas have been identified by the researchers for implementation of fuzzy expert systems in medical diagnosis. The surveys have been presented discussing utilization of fuzzy technology and fuzzy set theory in medicine and healthcare with an analysis of its possible future developments. Broadly, the studies seem to be contributed for the development of diagnostic techniques, quantification of medical expertise and application of fuzzy expert systems with their implementation in practice.

The survey of expert systems development using a literature review and classification of articles from 1995 to 2004 have been presented in order to explore how ES methodologies and applications have been developed during this period.³ Medicine, often on the borderline between science and art, are an excellent exponent: vagueness, linguistic uncertainty, hesitation, measurement imprecision, natural diversity, subjectivity – all these are prominently present in medical diagnosis.⁴ The scope for applications in diagnosis, therapy, image analysis, pattern recognition, patient monitoring, data analysis, etc have been reviewed.⁵⁻⁸ The surveys are presented on utilization of fuzzy logic control and monitoring in medical fields giving an overview of fuzzy technology developments and applications in the field of medicine. The survey on several areas of utility theory and techniques of decision analysis to the design and control of computational problem solving, computer based medical diagnosis systems and artificial intelligence have been reported.^{2, 9-14}

The analysis of present review implies that, about 8% papers are contributed in conducting reviews and surveys of expert systems in medical diagnosis by various researchers.

3. APPLICATIONS OF FUZZY EXPERT SYSTEMS IN MEDICAL DIAGNOSIS

Human reasoning and decision making is fuzzy, involving a high degree of vagueness in evidence and concept utilization and requires a high level of uncertainty management in medical diagnosis. There are several sources of imprecision and uncertainty in an expert systems domain. The solution to problems in the domain may be imprecise. For instance, this is true of most medical problems.¹⁵ Researchers have proposed numerous innovative fuzzy expert systems to deal with vagueness and complexity and offered the practical aids to users in the form of fuzzy expert systems. Intelligent medical systems are designed with a focus on specific disease for the support of decision process. The patient monitoring, prediction of conditions, handling of fuzzy queries as well as evaluation and comparison of the performances with existing practices are also been the areas of interests of researchers. The educational tools have been developed using fuzzy logic approach to assist the users.

In the reported studies, the need, importance, potential, necessity of fuzzification and approaches for designing of medical diagnosis expert systems are discussed.¹⁶⁻²⁰ Some studies have been conducted to verify the suitability of fuzzy set theory and its derived theories for developing knowledge based systems and fuzzy sets to model the medical concepts.^{12,21,22} Decision support systems for diagnostic purposes of human diseases helped patients and practitioners to a great extent.²³⁻²⁹ Developers have extended the use of fuzzy logic theory in designing disease specific and decision theoretic expert systems for common diseases.³⁰⁻³³ Fuzzy approach has been explored to deal with phenomenon of vagueness in the physician's style of thinking and computer assisted expert systems for decision making.³⁴⁻⁴¹ Computer assisted applications for patient's diagnosis and treatments seems to be the more recent area of interest.⁴²⁻⁴⁶ Web based fuzzy expert systems are reported for diagnosing human diseases.⁴⁷⁻⁴⁸ The areas in which diversified applications are developed using fuzzy logic are: fuzzy models for illness, heart and cardiovascular disease diagnosis, asthma, abdominal pain, tropical diseases, neurological diseases, medical analogy of consumption of drugs, malaria diagnosis,

diagnosis and treatment of diabetes, hepatobiliary disorder, diagnosis of male impotence, syndrome differentiation, diagnosis of lung and liver diseases, prostate diseases, lymph diseases, monitoring and control in intensive care units and operation theatres, diagnosis of chronic obstructive pulmonary diseases, diagnosis of cortical malformation, etc.^{49-71,164-172} The non-disease areas of applications are found to be in: x-ray mammography, interpretation of mammographic and ultrasound images, electrographic investigation of human body.⁷²⁻⁷⁴ The fuzzy expert system for different sounds produced by different organs in the human body using fuzzy logic toolbox of MATLAB has also been reported.⁷⁵ The application of fuzzy expert system and decision tree for selection of remedy in homoeopathy is among the rare application.⁷⁶ The other areas of applications of fuzzy logic are: prediction of aneurysm, fracture healing^{77,78} and in non-stationary FES, intuitionistic fuzzy sets.^{79,80}

The Fuzzy Expert System has proved its usefulness significantly in the medical diagnosis for the quantitative analysis and qualitative evaluation of medical data, consequently achieving the correctness of results. The computer based diagnostic tools and knowledge base certainly helps for early diagnosis of diseases. The development of web based applications and interfaces enabled the medical practitioners to share their experiences and expertise across the world. The development of disease specific applications using FES for medical diagnosis is observed to be the area of biggest interest of the researchers reporting 44% study dedicated to it.

4. METHODOLOGIES AND MODELLING OF FUZZY EXPERT SYSTEMS

Researchers have suggested numerous approaches and methodologies to deal with the diversified issues pertaining to medical diagnosis. The fuzzy systems are designed for modelling the available knowledge and thinking process of medical practitioners. Novel methodologies reported by various researchers comprises their use in the development of FES for : medical knowledge acquisition, development of hybrid systems, dealing with inconsistencies, treatment planning, advisory, monitoring and control of systems, parameters predictions, artificial thinking, genetic algorithm fuzzy approach and others.

Fuzzy models are widely used for the development of decision support systems based on the expert's knowledge and observations in clinical context. The novel methodologies are presented for physician's decisions in medical informatics, medical problems solving and for the assessment of treatment planning decision process in diseases and therapies.⁸¹⁻⁸³ The studies are intended to develop conceptual models of fuzzy knowledge systems.⁸⁴ Problem solving algorithms are proposed for data handling, pattern recognition, fuzzy segmentation of MRI data and diagnosis of diseases using genetic algorithm fuzzy approach.⁸⁵⁻⁹⁰ As the novel approach, fuzzy logic, neural network and expert systems are combined to build hybrid systems for the diagnosis. The hybrid and intelligent systems are reported to deal with complex medical problems and diagnosis, treatment consultation and medical data classification.⁹¹⁻⁹⁵ Researchers have addressed the issues and systems to predict the risks in terms of anticipating critical parameters for control, enhance control strategies to diagnose diseases and diagnosis regarding disorders of

specific organs.⁹⁶⁻⁹⁹ Medical advisory systems for deciding the quantum of medicine, taking online measurements, monitoring, controlling of parameters are proposed.¹⁰⁰⁻¹⁰² Computer aided medical diagnosis, medical image processing, noise reduction in medical images, simulation and automated generation of fuzzy models and expert systems using generic methodology are the areas that alleviated FES to the new height and could provide a way of generating solutions based on stored data.¹⁰³⁻¹¹⁰ Medical data classification, data transformation system, feature extraction and investigation are the areas where improved performance has been reported.¹¹¹⁻¹¹³ The fuzzy neural diagnostic systems are proposed by proposing novel models to combine the neural network capabilities and the fuzzy logic approach.¹¹⁴⁻¹¹⁶ Hamid investigated broad range of methods for incorporating multimedia expert system services in the world of heart diseases diagnosis, training and education.¹¹⁷

The suggested approaches and methods are successfully implemented by various researchers in the medical field. The medical practitioners and patients are using FES laden diagnostic tool with an ease and effective way. Investigation implies that, 21% papers are contributed towards the modeling and methodologies. The inclination of most of the researchers is found towards the development of fuzzy expert systems specific to expertise and problem oriented domain. It is suggested that different social science methodologies, such as psychology, cognitive science, and human behavior could implement FES as another kind of methodology. Integration of qualitative, quantitative and scientific methods and integration of FES methodologies studies may broaden the horizon of the research in medical field.

5. NEURO-FUZZY APPROACHES

Fuzzy logic and neural networks are complementary technologies and when brought together can provide intelligent systems. Neuro-fuzzy model incorporates the generic advantages of artificial neural networks in modeling imprecise data and qualitative knowledge as well as transmission of uncertainty. Researchers used the neuro-fuzzy approaches to build more intelligent decision making systems and presented the applications and supportive tools for the physicians.

The overviews of medical applications are presented involving neural networks and artificial intelligent techniques.^{118,119} The disease specific diagnostic tools and generic tools are developed using neuro-fuzzy approach.^{120,121} The study has been reported to improve the diagnostic accuracy of diseases.¹²² Neuro-fuzzy approach also has been used to derive logical inference and statistical inference for prediction or early diagnosis of diseases and risk factors.¹²³⁻¹²⁵ The significant studies using neuro-fuzzy approaches pertained to artificial neural network in disease diagnosis, fuzzy cluster means analysis, medical pattern classification and classifier to take some decisions are presented.^{126-130,173} Researchers proposed the intelligent perception-based systems, hybrid approaches for development of adaptive neuro-fuzzy inference systems and medical expert systems.¹³¹⁻¹³³ The algorithms for Machine learning and pattern classification are proposed using neural network.^{134,135} Design of adaptive neuro-fuzzy systems for the detection of glaucoma, ophthalmic artery stenosis, electrocardiographic changes in patients and facial expression analysis are the applications reported using neuro-fuzzy approach.¹³⁶⁻¹³⁹

Fuzzy logic provides a high level framework for approximate reasoning that can appropriately handle both the uncertainty and imprecision in linguistic semantics, model expert heuristics and provides requisite high level organizing principles. The neural network provides self-organizing substrates for low level representation of information with on-line adaptation capabilities. The communications between medical scientists and computer engineers have lead to an interdisciplinary advance in the development of intelligent supporting tools and systems. The analysis implies that approximately 13% papers are contributed in the development of neuro-fuzzy based expert systems in the field of medical diagnosis.

6. FUZZY EXPERT SYSTEM SHELLS AND FRAMEWORKS

The expert systems are developed by many researchers using specialized software tools called “shells” and their architectures are presented. The expert system shell can hold the uncertainty properly for use in attractive domains of applications that deal with imprecise information. The expert system shells come equipped with an inference mechanism (backward chaining, forward chaining or both) and require knowledge to be entered according to a specified format. The object oriented expert system shells are also developed to link the external databases with expert systems. The literature survey reveals that, the commercially available expert system shells are rigorously used to write the application specific rule-bases. Also, the expert system shells are developed with application specific inference shells. Many authors have presented the frameworks for automatic generation of fuzzy expert systems with reference to typical diseases and decision support systems.

It has been found that the frameworks are developed for generation of a fuzzy expert systems with respect to specific diseases, general purpose diagnostic systems as well as for counseling of personal health.¹⁴⁰⁻¹⁴² The architectures are proposed for the implementation and improving performance of a rule based diagnostic decision support systems related to medical diagnosis.¹⁴³⁻¹⁴⁵ The powerful, generic as well as hybrid expert systems for diagnosis and remodeling of existing systems are also been reported.¹⁴⁶⁻¹⁴⁸ The design of expert system frameworks for medical treatment and prevention of high risks related with the human health widened the scope for implementation of fuzzy concept in medical field.¹⁴⁹ The studies on probabilistic interpretation and statistical analysis of medical data have been presented.^{150,151} Medical decision support systems are designed in the form of large scale expert system shells and used for augmenting large knowledge bases.^{152,153} Suitability of the computer systems using fuzzy methods and computerized monitoring and medical decision making systems have been reported.¹⁵⁴⁻¹⁵⁸ Fuzzy frameworks are also developed for the medical imaging, interface program designing and knowledge mining.¹⁵⁹⁻¹⁶¹ The novel object oriented frameworks to construct fuzzy expert systems are proposed.^{162,163} The integration of two or more different knowledge representation methods has been identified as a very active research area in Artificial Intelligence.

The expert system shells and frameworks are developed and utilized so far for the tasks of quantifying medical concepts, data interpretation and constructing inferential knowledge from the knowledge bases. The generic aspects of many

proposed fuzzy architectures enabled the automated generation of fuzzy models for mining the medical knowledge and its deployment in medical field. The analysis implies that, about 14% papers are contributed to the development of fuzzy expert system shells and frameworks in the field of medical diagnosis.

7. TRENDS IN RESEARCH OF MEDICAL FUZZY EXPERT SYSTEMS

The use of fuzzy logic for medical diagnosis has the history of almost three decades. Technologists and physicians have put their efforts for the exploration of “fuzzy for medical diagnosis” applicability. The study reveals that, fuzzy concept has been successfully implemented in the medical field and major quantum of the researchers’ efforts, i.e. 44% contributed to development of the diversified applications. The implementation of innovative applications using fuzzy concept in medical diagnosis is the second largest area where studies are dedicated. About 40% innovative applications are found to be reported in the entire review. The share of conceptual studies and reviews and surveys are found to be 14% and 8% respectively. Fig. 2 shows the distribution of referred articles based on the major classification.

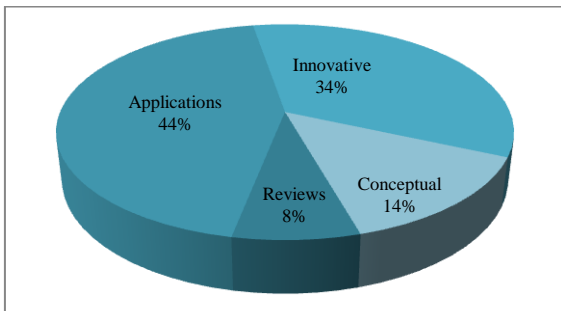


Fig 2: Distribution of articles based on major classification

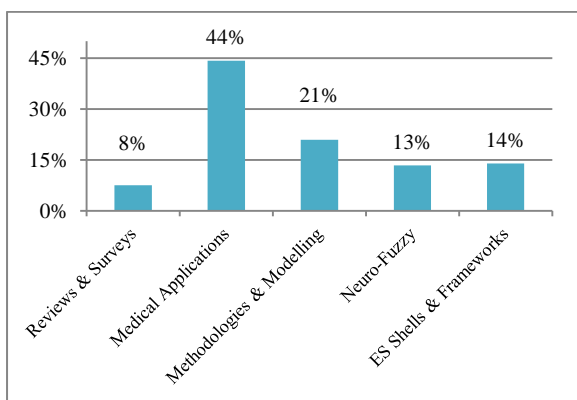


Fig 3: Percentage distribution of publications based on classification of articles

The review has been performed and articles are classified into the five distinct categories as shown in Fig. 3. It shows the percentage distribution of publications based on classification of the articles.

It has been found that, almost every aspect of the fuzzy concept had been undertaken by the researchers for their studies. To consolidate the overall idea of reported studies, it was necessary to classify the publications in some distinct categories based on the similarity of the interests of the researchers. Apart from the studies dedicated to development of diversified applications and conducting reviews and surveys, it has been notified that, 21% reported research is devoted towards the development of methodologies and models. The share of studies conducted at architectural development level of fuzzy expert system shells and frameworks have been also found to be significant, i.e. 14%. The neuro-fuzzy approach has been used by many researchers and developed many fuzzy expert systems incorporating artificial intelligence to it. The investigation reveals that, 13% studies are contributed to the development of neuro-fuzzy based expert systems.

Fig. 4 shows the trend of research in medical fuzzy expert systems in last two & half decades. The graph shows an exponential growth in the interests invested by various researchers for the inception and nourishment of fuzzy concept in the medical field. Up to the year 2000, the penetration of fuzzy concept in medical field seems to be at par. But, the recent span shows the exponential growth and more attention of researchers toward the development of fuzzy based expert systems specific to medical diagnosis. This accelerated trend intensifies the demand for more focus on the development of more intelligent medical fuzzy expert systems.

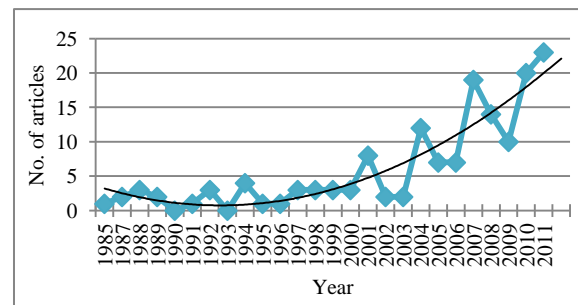


Fig 4: Trend of research in medical fuzzy expert systems in last two & half decades

8. FUTURE SCOPE OF FUZZY EXPERT SYSTEMS IN MEDICAL DIAGNOSIS

The sources state that, the limitations of medical decision making systems do not result from their limited computational power, but lies in the unavailability of intellectual interface between medical practitioners and computers. Till date, almost 100% medical practitioners are using computers, but many of them still do not prefer to use the expert systems as a diagnostic aid. It proved its usefulness significantly in the medical diagnosis for quantitative analysis and qualitative evaluation of medical data, consequently achieving the correctness of results. The computer based diagnostic tools and knowledgebase certainly helps for early diagnosis of diseases. To bridge the gap, more intelligent software embedded with intelligent interfaces needs to introduce along with the expert systems. This will use the full potential of fuzzy technology in medical diagnosis segment. In future, expert systems may be developed that will understand human thinking pattern, human perceptions, gestures and human

moods. The development of interfaces and sensory systems to acquire symptomatic parameters, their mapping and input mapping of responses of the human organs will be the potential paradigm of the research in future. Such expert systems will be termed as the *third generation fuzzy expert systems*. Development of the interdisciplinary and hybrid systems (third generation expert systems) seems the potential area for exploration of the concept.

9. CONCLUSIONS

Fuzzy Expert System technology has been growing rapidly during last three decades. The first generation expert systems have had some limitations. The focus of development of these expert systems was upon simulating the human knowledge and reasoning strategy of inference engine. The expert systems were designed for specific task and did not offer the solution for other tasks. Whereas, the second generation expert systems are generic in nature, in which common frameworks are suggested for development of the expert systems. Development of modeling methodologies, shells and frameworks are the major areas where key contributions of fuzzy technology has been observed. The initial studies on fuzzy expert systems were concerned with the concepts and representation of domain knowledge. In between the years 1990-2000, several researchers focused their attention toward the development of hybrid, fuzzy-neural expert systems and case based systems by implementing the domain knowledge. Research in the recent decade had contributed for the development of computer aided expert systems, development of multi-media based systems and suggested novel modeling approaches. The highest volume of publications on fuzzy expert systems in medical diagnosis, i.e. 62% occurred between the years 2004 to 2011. Despite enormous developments those have been taken place in the medical field, logical thinking of medical practitioners play significant role in making the diagnosis decisions. The computers and software are not capable enough to resolve entirely issues pertaining to human logical thinking and perceptions. The development of fuzzy expert systems with a blending of more intelligence, interactivity, interdisciplinary and hybrid systems are yet the potential area to explore in medical field in future and such systems will be called as the third generation expert systems.

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