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Expert System for Disease Diagnosis in Soybean-ESDDS

Savita Kolhe[1], Raj Kamal[2], Harvinder S. Saini[3] and G.K. Gupta[1]
[1]*Directorate of Soybean Research (ICAR), Khandwa Road, Indore*
[2]*School of Computer Science and Electronics, Devi Ahilya University, Khandwa Road, Indore*
[3]*Guru Nanak Institutions, Ibrahimpatnam, Hyderabad*

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SUMMARY

The paper describes the development of expert system for disease diagnosis in soybean. It explains the methodology for development of knowledge-based expert system. The different components of the expert system are explained. The inference engine of the system has been developed as Object-Oriented (O-O) inference model using O-O programming. The O-O inference model involves disease management case studies, fuzzy logic algebra, rule-promotion strategy, rule-patterns experience and statistical methods in the form of objects as an analytical tool and predicts accurate disease. The knowledge base is implemented in the form of relational database using SQL Server. The user interface of the software is modeled based on 3-tier architecture design using ASP.NET. The system evaluation study includes verification and validation processes. The interface of system is evaluated on ten design features. The validation process was conducted by a team of twenty agriculture researchers with different level of experiences in agriculture. The evaluators were highly satisfied with the user interface and found it user-friendly. The overall average rating given by the users was more than 8 on a 1-10 point scale. The inference drawing process of inference engine was significantly improved by application of new fuzzy-logic rule-promotion approach. The number of successful diagnoses was increased from 65% upto 92.4% by applying new approach. The system as a whole is a powerful means for transfer of soybean pathological technologies to practices over the web. The inference model developed in this work can be reused for other crops also.

Keywords: Disease diagnosis, Expert system, Fuzzy-logic, Inference engine, Knowledge base, Soybean disease diagnosis.

1. INTRODUCTION

Expert systems (ES) have been used successfully in the diversified application areas. For example, there are ES that can be used for insect-pest management, schedule routes for delivery vehicles, financial forecasts, diagnose crop diseases, diagnosis of plant nutrient deficiency, crop cultivation etc. (Shortliffe 1976, Latin 1987, Batchelor *et al.* 1989, Plant *et al.* 1989, Deer-Ascough 1992, Tao and Zhang 1992, Turban 1992, Boyd 1994, Cernohorska 1995, Yuan-CunXing *et al.* 2003, Kolhe *et al.* 2007). ES developed in the field of agriculture combines the experimental and experiential agriculture knowledge, with the intuitive reasoning skills of many specialists and helps the farmers in taking appropriate decision. Some ES are designed to replace the human experts, while others are designed to aid them in the mundane work (Waterman 1986). Replacement of human expert is not possible in many cases, and in those cases ES can be of much use to provide expert level guidance/assistance to perform tasks, which require more specialized expert knowledge.

Agriculture is an important area. A number of existing and emerging biotic (living) factors like

Corresponding author : Savita Kolhe
E-mail address : savita_dakhane@yahoo.com, savitasoham@gmail.com

diseases, insects, weeds etc. and abiotic (non-living) factors like nutritional deficiencies, environmental conditions, soil conditions etc. limit the high yield potential of crops and thus hamper the overall productivity. Therefore, to achieve sustainable agricultural production it is very much needed to incorporate modern technology into traditional crop protection technology. The human expert for this purpose are very limited in number and are not available everywhere. Dependence on the human expert can be minimized if his/her expertise can be transferred into a computer system. Many diagnostic ES are already developed in the past (Michalski *et al*. 1983, Caristi *et al*. 1987, Latin *et al*. 1987, Donahue *et al*. 1991, Sanchez *et al*. 1993, Zhang *et al*. 1993, Boyd and Sun 1994, Yialouris *et al*. 1996, 1997, Cirio *et al*. 1998, Airu and Wang 1999). All these diagnostic ES were single-user, standalone and conventional type of system and they also lacked web connectivity. Therefore, an ES is developed for disease diagnosis in soybean to get this expertise available on World Wide Web (WWW).

2. COMPONENTS OF ESDDS

The standard architecture of Knowledge-Based Expert System (KBES) for disease diagnosis in Soybean is shown in Fig. 1. Its different components are discussed below.

2.1 Knowledge Base

It contains the relevant knowledge necessary for understanding, formulating and solving soybean disease diagnosis problems. It includes two basic elements – disease facts and disease rules. The disease facts include basic data required for creating the disease rules and providing disease related information to the users. The disease rules are the diagnostic rules that are used by the system to diagnose a particular disease and to suggest an appropriate control measure. The diagnostic knowledge in ESDDS is divided into the knowledge domains- 'date of sowing' of the crops as main-domain and 'part affected' as sub-domain.

All the crop disease symptoms are classified according to the following criteria (Kolhe *et al.* 2010).

- crop age based on date of sowing (30, 60, 90, 120 days after sowing)
- plant growth stages (seed, seedling and well grown plant)
- part of the plant on which the infection is observed (root, leaf, seedling stem, bud, pod, seed etc.)
- type of infection (spots, lesions, pustules, fungal structures, mycelium, mottling etc.)
- type of expression of the infection (brown, water soaked, irregular, sunken, raised etc.)

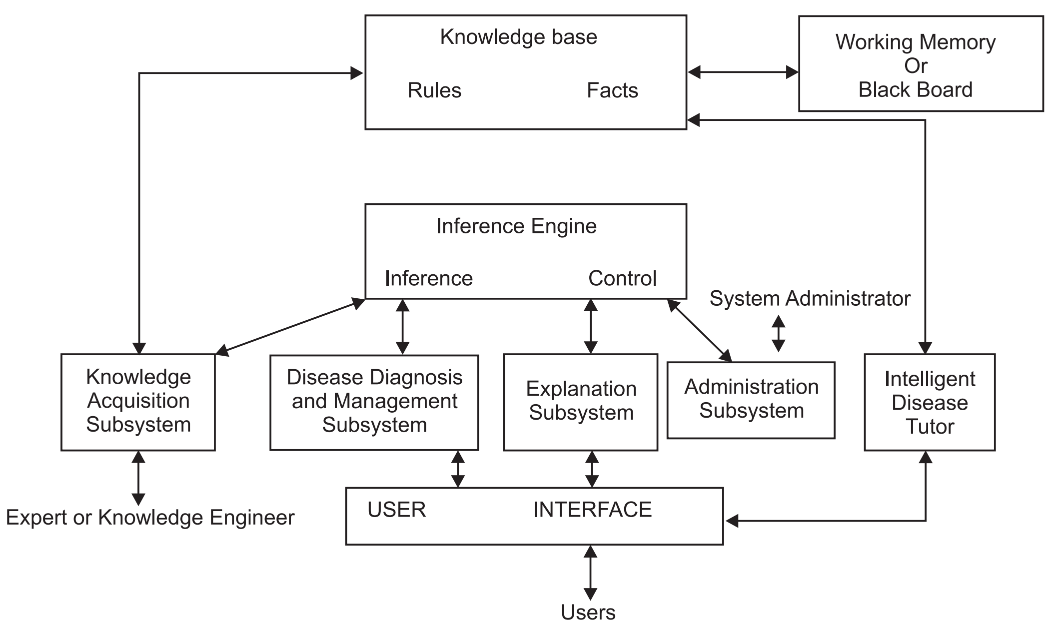

Fig. 1. Architecture of a KBES for disease diagnosis in Soybean

The knowledge base in ESDDS is represented in the form of rule base as it has major advantages (i) rules are easy to understand and communicate as they are in natural form of knowledge, (ii) inference and explanation are easily derived, (iii) modifications and maintenance are relatively easy and (iv) uncertainty is easily combined with rules. Each rule is often independent of all others. A numeric value is associated with each piece of information in the system to deal with uncertainty. The numeric value represents the certainty with which the information is known. It is called confidence factor. These confidence factors (Column 5 of Table 1) are initially given by the domain expert based on their belief and confidence in the piece of information. The object-attribute-value (O-A-V) knowledge representation method was followed (Harmon and King 1985) as it easily fits into a rule-based ES. For example, the symptoms for Bacterial blight disease in soybean as observed on well grown plant stage at crop age between 60 and 90 days can be represented as Table 1.

The conditions of each rule is connected with other rule by *And* (conjunction), *Or* (disjunction), *material implication* and *negation.* The keywords viz rule, IF, THEN, AND, OR etc are defined by the user. The confidence factor of a rule is calculated according to the following fuzzy logic algebra (Yialouris and Sideridis 1996).

If CF(A) and CF(B) is the confidence factors of conditions A and B, respectively, then

CF(A AND B) = min [CF(A), CF(B)],

CF(A OR B) = max [CF(A), CF(B)],

NOT[CF(A)] = 1 – CF(A).

With this provision the user can write his/her own KB in his/her own language.

Following rules are derived and the confidence factor is shown in the bracket at the end.

R258 : IF Atmosphere temperature is Low or Moderate

AND Relative humidity is high

THEN *Ignore* Bacterial blight (0.2)

Table 1. Tabular representation of the symptoms of Bacterial blight disease in O-A-V form

Rule condition No.	Object	Attribute	Value	Confidence Factor
OAV116	Atmosphere temperature	Is	Low or Moderate	0.2
OAV75	Relative humidity	Is	High	0.2
OAV118	Small, angular, translucent, not raised at center, water soaked yellow to light brown spots	Appear on	Leaves	0.8
OAV119	Older spots	Turn to	Reddish brown to black surrounded by water soaked margin with yellowish green halo border	0.4
OAV120	Older spots	Appear as	Centrally torn	0.4
OAV121	Older leaves	Appear as	Ragged or shredded	0.6
OAV124	Small or large water soaked lesions	Appear on	Stem	0.4
OAV122	Small or large water soaked lesions	Appear on	Petioles	0.4
OAV123	Small or large water soaked lesions	Appear on	Pods	0.4

R263 : IF Small, angular, translucent, not raised at center, water soaked yellow to light brown spots Appear on Leaves

THEN *probably* disease is Bacterial blight (0.8)

R264 : IF Older spots Turn to Reddish brown to black surrounded by water soaked margin with yellowish green halo border

AND Older spots Appear as centrally torn

THEN *slight evidence* of Bacterial blight (0.4)

R265 : IF Older leaves Appear as Ragged or shredded

THEN *slight evidence* of Bacterial blight (0.6)

R266 : IF Small or large water soaked lesions Appear on Stem

AND petioles

AND pods

THEN *slight evidence* of Bacterial blight (0.4)

Finally, this knowledge base is implemented in the form of relational database tables using SQL Server in computer. The part of database relationship diagram is shown in Fig. 2. The final knowledge base contains 566 disease rules for 25 soybean diseases.

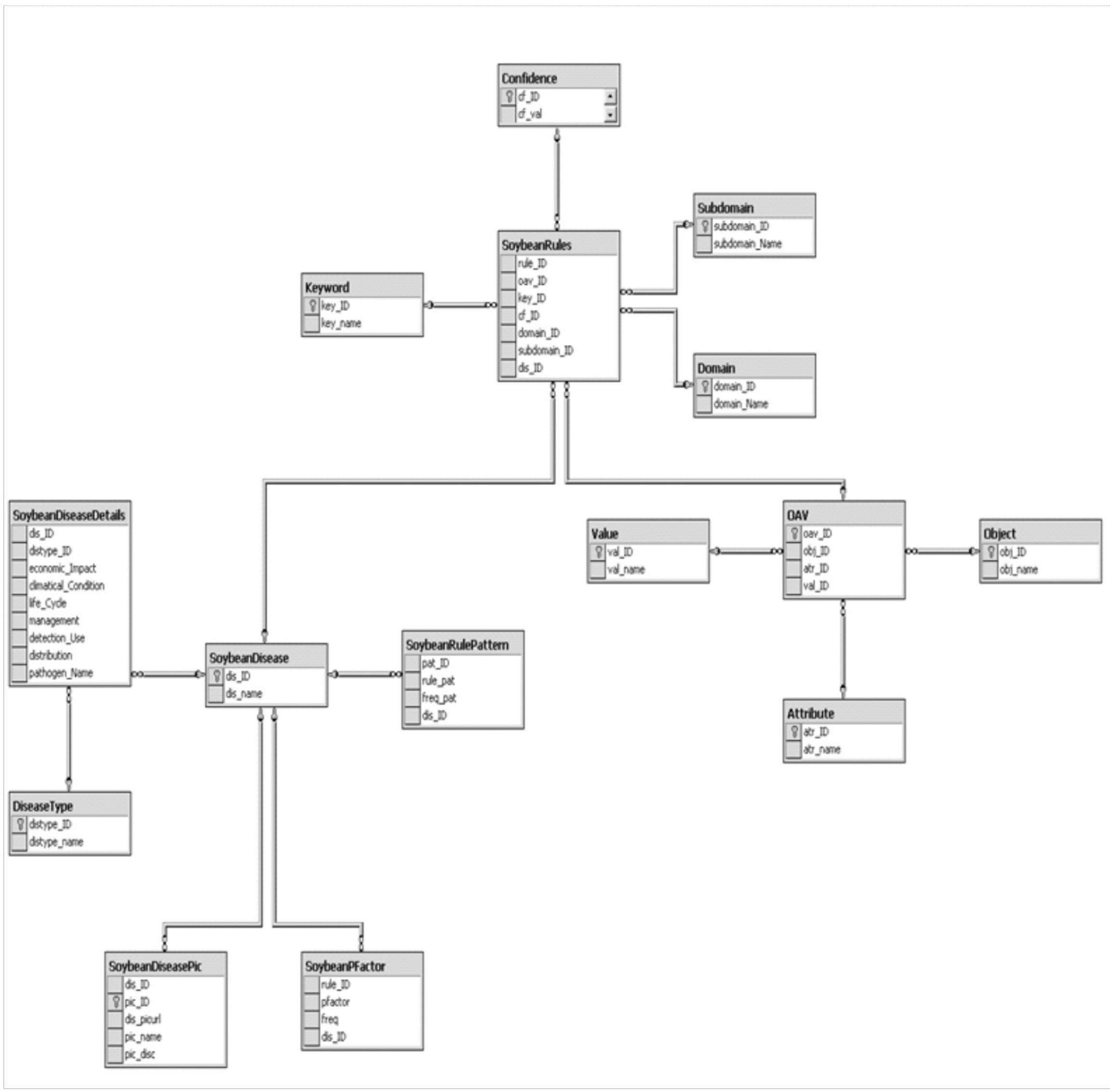

Fig. 2. A part of the database relationship diagram.

2.2 Inference Engine

Inference engine is the "brain" of the ES. It also acts as *control structure* or *rule interpreter* (in rule-based ES). It is a computer program that provides a methodology for (a) reasoning about information in the knowledge base and on the blackboard and (b) formulating conclusions. The inference engine of ESDDS has been developed as O-O inference model using O-O programming. It is developed using C# and ASP.NET.

The O-O inference model involves disease management case studies, fuzzy logic algebra, rule-promotion strategy (Kolhe *et al.* 2011a), rule-patterns experience and statistical methods in the form of objects as an analytical tool and predict accurate disease. In rule-promotion strategy an improved confidence factor is assigned to all the rules based on the results of the earlier diagnosis session. If a rule is repetitively used in successful diagnostic conclusion it is promoted to higher confidence-level by increasing its confidence factor and if it is used in unsuccessful diagnostic conclusion it is demoted to lower confidence-level by decreasing its confidence factor. The session is successful if it results in a correct diagnostic conclusion acceptable to the disease expert. The inference model also maintains a log of the Rule Patterns that are continuously used in every successful decision for a particular disease. In this way the diagnostic conclusion is improved after every successful session.

2.3 Knowledge Acquisition Subsystem (KAS)

The KAS is a subsystem of the ESDDS and is designed for efficient handling of the soybean disease knowledge during the entire process of knowledge acquisition, classification, representation, processing and final storage. This provides a strong and reliable knowledge base support for the ESDDS. The domain expert can easily enter and manage the disease knowledge on-line with the help of web interface of KAS as shown in Fig. 3.

2.4 Disease Diagnosis and Management System

It is a subsystem of ESDDS that provides the user with a friendly and effective web-interface for correct disease diagnosis and its appropriate timely management. The extension workers and agencies advising farmers can guide the ill-literate farmers to take appropriate measures to prevent the devastating effects of the disease outbreaks. The user interface integrated with the text-to-voice support provided in the form of icon as  on every web-form as shown in Figs. 4 to 7. The Microsoft Speech SDK (version 5.1) is used to develop text-to-voice user interface.

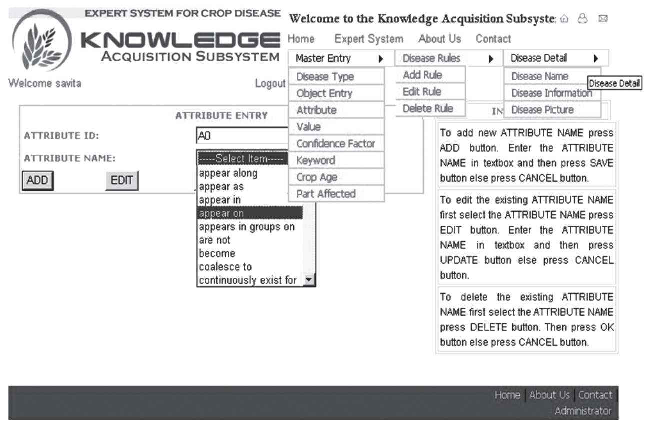

Fig. 3. The web interface of Knowledge Acquisition Subsystem

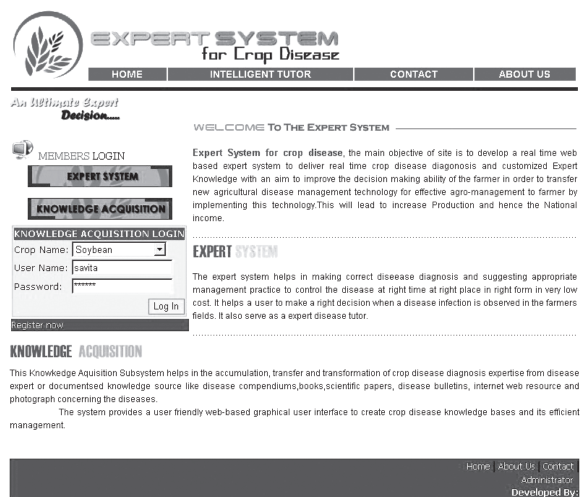

Fig. 4. The main web page of ESDDS

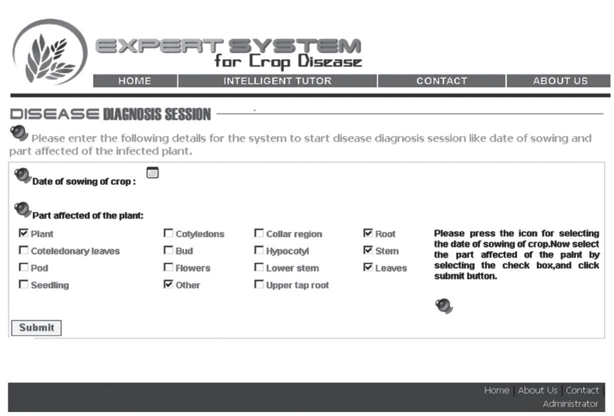

Fig. 5. The web form for entering initial inputs into the ESDDS for disease diagnosis

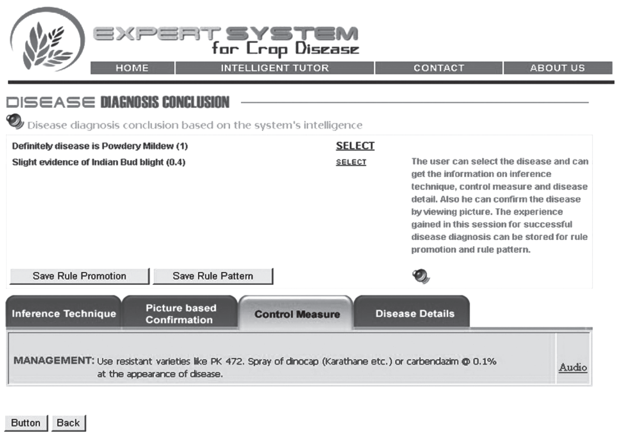

Fig. 6. The user interface showing the diagnostic conclusion with control measure

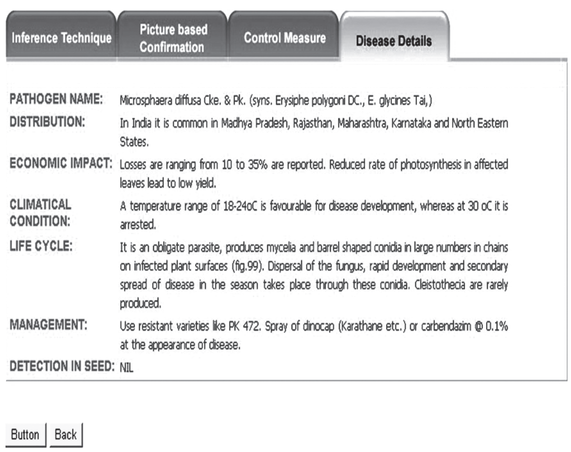

Fig. 7. The web interface showing the disease information

2.5 Intelligent Disease Tutor

The "Intelligent Tutor" is a sub-system of ESDDS that starts working by clicking its menu-option (Fig. 4). No inferences are drawn only disease information is retrieved on useful disease related aspects like pathogen, geographic distribution, economic impact, favourable climatic conditions, detection methods and effective integrated management of practices. It serves as useful interactive audio-visual training tool for providing pathological trainings with the help of multimedia effects, coloured pictures, audio, videos, texts and graphics.

2.6 Blackboard (Workplace)

Blackboard is one of the basic components of ES. It is an area of working memory set aside as a database for the description of a current problem as specified by the input data. It is used for recording the intermediate results and decisions. In ESDDS, it is defined as a database table named "BlackBrd" in SQL Server. With its help only the system retrieves all the knowledge and inference technique used by the system to reach a particular diagnostic conclusion.

2.7 Explanation Subsystem (Justifier)

It acts as a justifier and provides an interface to explain the complete reasoning process used to give the final decision. It explains about the detailed reasoning process, inferences drawn along with picture-based confirmation of the diagnosis result and other disease related information. This is in the form of text, pictures and human voice/audio.

2.8 Administration Subsystem

It manages and maintains different users of ESDDS. It helps in updating or adding new users with different rights for security purposes. The users are categorized into different levels based on their rights (Fig. 8). Super Admin has full rights and can provide username and password to all users. Admin is the second level authority of the system and can provide username and password to Knowledge Management users who are basically the disease experts. ES user has rights to use the system for disease diagnosis purposes. Guest user has rights to use only the Intelligent Disease Tutor to get the crop disease basic knowledge on different aspects.

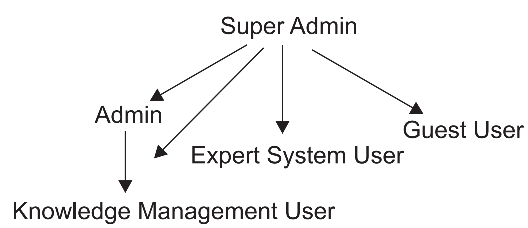

Fig. 8. Different levels of users based on their rights

3. INFERENCING IN ESDDS

There are two methods for controlling inference in rule-based ES: *forward chaining* (or data-driven) and *backward chaining* (or goal-driven). In ESDDS, we used the combination of forward and backward chaining inference methods.

During the diagnosis process if the symptoms of the disease are known and are provided as inputs, then using forward chaining mechanism these symptom conditions are matched and the system tries to identify the correct disease. In this case “IF” part of the rule condition is known to the system and it tries to find “THEN” part therefore forward chaining is applied. But sometimes when sufficient symptoms are not given by user as symptom input, then based on the symptoms provided it identifies the possible diseases and it applies backward chaining mechanism and tries to provide more disease symptoms for taking more users’ inputs. Thus mostly during diagnosis process a combination of forward and backward chaining search process is used until it reaches the final diagnostic conclusion. This is explained with the following example:

If the user gives following initial input:

Part affected = “lower stem”

With this information by using backward chaining search process it displays the user the following symptoms for taking input:

Minute black sclerotia appear on cortical tissue

Minute black sclerotia appear on pith region

IF user selects both of inputs then by using the forward chaining search process the following rule is fired:

IF Part Affected = “lower stem”

AND Minute Black Sclerotia appear on Cortical Tissue

AND Minute Black Sclerotia appear on Pith Region

By using forward chaining it searches the following final conclusion :

THEN definitely disease is charcoal rot

The search process works in this way in inference engine of ESDDS.

3.1 Uncertainty Management

Inferencing with uncertainty in diagnostic ES is very important step to reach a correct diagnostic conclusion. There are three basic methods to deal with uncertain knowledge- numeric, graphical and symbolic. The method of fuzzy logic provides a special symbolic representation combined with numbers. It is useful for uncertainty management because it is an effective and accurate way to describe human perceptions of decision-making problems. It has been successfully used in ES for the management of uncertainty and performing inferences in the situations where knowledge is vague, inexact, imperfect and not completely reliable (Zadeh 1996). This is the case in diagnostic ES. A new rule-promotion fuzzy-logic approach was used in ESDDS for handling uncertainty successfully.

3.2 Fuzzy-logic Approach

The confidence factor (CF) represents the confidence that we have in a piece of evidence. There are numerous ways in which confidence factors can be defined, and how they are combined during the inference process. The most general way is the use of *fuzzy logic*, invented by Lotfi Zadeh (Zadeh 1965). It is a multi-valued logic to express different degrees of certainty or uncertainty of assertions. The domain expert’s confidence in a rule remains unchanged in the conventional rule based expert system, so the inference drawing power of the system also remains the same over the years. The inference technique is made more powerful in our system by the introduction of a new approach called rule-promotion (Kolhe *et al.* 2011c). It is based on the natural belief that the confidence in rules increases gradually if the rules repetitively result in right decision. Thus, the difference in conventional inference drawing approach and our new rule promotion approach is that former methods attach constant values of CF to rules whereas we are applying dynamic values of CF based on fuzzy logic. Conventional methods use the same original CF as initially given by domain experts for all the decisions throughout the life time of the ES while in our approach for each new session, an improved CF is assigned to all the rules based on the results of the earlier diagnosis session. So, if a rule is repetitively being used in successful conclusion it is promoted to higher confidence-level by increasing its CF. This new CF of the rule is its promoted CF. The final diagnostic decision is taken based on promoted CF instead of initial CF. This has resulted into significant improvement in the inferences drawn by increased number of successful diagnoses after every successive diagnostic session.

4. SOFTWARE ARCHITECTURE MODEL

The user interface of ESDDS software is modeled based on 3-tier architecture design using ASP.NET. It contains (i) Presentation Layer, (ii) Business Logic Layer and (iii) Data Access Layer (DAL) as shown in Fig. 9 (Kolhe *et al.* 2011b).

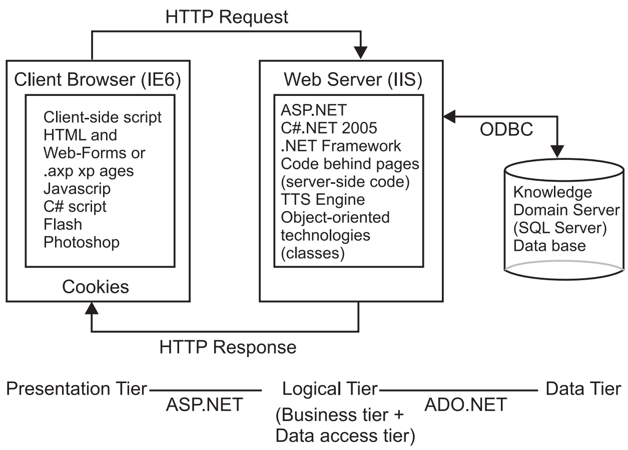

Fig. 9. Representation of three-tier architecture design of ESDDS

The presentation layer contains more than thirty .aspx pages. These pages are used to get the inputs and to give the outputs to the users.

The business logic layer contains more than thirty code-behind pages created using C# programming language. It stores User-authentication code, Knowledge management, Knowledge reasoning mechanism, Control strategy and Inference model based on rule promotion approach.

The Data Access Layer contains knowledge of ESDDS. It stores facts and knowledge in 31 database tables developed in SQL Server (Fig. 2). The Open Database Connectivity (ODBC) method is used.

5. SYSTEM EVALUATION

The overall system evaluation includes verification and validation processes (Harrison 1991).

5.1 Verification

The verification process ensures that the knowledge in the system is consistent, complete and correct according to required specification. During this process, the knowledge base was verified after compilation of all the rules and necessary alterations and additions were made to ensure accuracy. All the possible errors and bugs in the system were located. It was also ensured iteratively that the system performance was as needed. All the possible logical pathways were traced to determine their correctness. The system programme was run many times by providing different combinations of all the possible inputs. The conclusion drawn for each diagnostic consultation was crosschecked by pathologists of soybean crop at Directorate of Soybean Research, Indore.

5.2 Validation

Validation is an important, but often neglected, part of the development of a knowledge-based expert system (Bonnet *et al*. 1988). Its definition is often confused. It is often used interchangeably with two other terms commonly used in the testing of expert systems-verification and evaluation (Turban 1993). The definition of O'Keefe *et al*. (1987) was followed in this context where validation refers to building the right system. It means ensuring that a system performs with an acceptable level of accuracy.

The methodology of validation by the end users or live testing (Mosqueira and Monet-Bonillo 2000 and Gonzalez-Andujar *et al*. 2006) was used. The validation process was conducted by a team of 20 agriculture researchers with different level of experiences in agriculture (i) less than three years, (ii) between three to five years and (iii) more than five years. The group was the combination of different level of computer skills and exposure to agriculture websites or systems also. The system evaluators were asked to mark a questionnaire on 10 user interface design features-Ease of use, Navigation, Cognitive load, Mapping, Screen design, Knowledge space compatibility, Information presentation, Media integration, Aesthetics and Overall functionality. Each of the evaluation parameter was rated on a continuum (e.g. difficult-easy) with a 1-10 point scale with 1 being highly negative and 10 being highly positive. The overall average rating was more than 8 points. It indicates that most of the evaluators were satisfied with the user interface. It also showed that the interface developed was comfortably used by the evaluators.

Each team member also tested the system by running 8 disease cases to check the accuracy of the system. A total of 160 disease identification cases were performed covering nearly 25 diseases. With the help of ESDDS, the evaluators were able to diagnose nearly 65% of diseases correctly without applying rule-promotion initially. With the successive application of the rule-promotion approach, the number of successful diagnoses were increased upto 92.4% (Kolhe *et al.* 2011c). This shows that the new rule-promotion strategy could be successfully applied to the expert systems with improved diagnostic results every time.

6. CONCLUSION AND FUTURE WORKS

The ESDDS software was developed on 3-tier architecture design using ASP.NET and integrating Text-To-Speech (TTS). Analysis, design and implementation of inference process were done using O-O principles. This resulted in the development of generic and highly-configurable inference-model that can be reused as such in diagnostic ES of other crops also.

The users have been found to be highly satisfied with interactive interface design of the system. This was observed by the overall ratings for ten user interface parameters. The overall average rating was more than 8 on a 1-10 point scale. The capability of providing audio information in human voice by using TTS conversion tool in the interface design has attracted many users. A user can conveniently use the interface without reading on the screens but by just hearing the information written on the screens. The users found that the system can serve as an educational/training tool and an intelligent crop disease tutor. It can thus augment the conventional educational methodologies in specific courses in plant pathology. The application of rule-promotion fuzzy-logic approach has shown significant improvement in the inferences drawn during successive diagnostic sessions.

The development of a real-time ESDDS can help soybean growers in disease diagnosis, in taking appropriate quick decision/judgment in real time field conditions by harnessing the analytical and decision-making capabilities of disease experts. The ESDDS as a whole can be a powerful means for transfer of soybean pathological technologies to practices over the web.

The extent of yield losses due to diseases can be minimized with the real-time application of the system. It is by spreading awareness on pre-disposing climatic factors and making the exact diagnosis and management expertise available in text, graphics and audio forms on World Wide Web at right time at right place at a very low cost.

As a part of future work, the same application can be used for expert disease diagnosis of other crops by storing its knowledge in the same system. It can be easily integrated with TTS engine of other regional languages that are compatible with .NET applications. This will solve the problem of multiple regional languages in India. In future, it can be integrated with a suitable disease forecast model so that we can make future predictions about the disease attack.

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