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Expert System for Greenhouse Production Management

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1. Introduction

Greenhouse is a kind of agricultural building structure with glass or plastic roof, where the vegetables or flowers can grow well year round by controlling the inside climatic environment. Fig. 1 shows commercial multispan greenhouses in China. The closed environment of a greenhouse has its own unique requirements, compared with outdoor production. Pests and diseases, and extremes of heat and humidity, have to be controlled, and fertigation is necessary to provide water and nutrients. Significant inputs of heat and light may be required, particularly with winter production of warm-weather vegetables. So greenhouse cost-effectiveness can not be ignored.

Fig. 1. Modern commercial greenhouses

Greenhouses are increasingly important in the food supply of high latitude countries and regions, especially Northern China, because they can allow certain crops to be grown year round such as lettuce and tomato.

Greenhouses protect crops from too much heat or cold, shield plants from dust storms and blizzards, and help to keep out pests or diseases. Light and temperature control allows greenhouses to turn inarable land into arable land. Hydroponics can be used in greenhouses as well to make the most use of the interior space.

Therefore, greenhouse industry is one of the most important parts and symbol of modern agriculture, since it can provide abundant fresh products stably and sustainably. However, greenhouse production process is much more complicated, compared with outdoor production. Precision management is badly needed under such controlled space. Generally, greenhouse system consists of the following elements – surrounding structures, covering, cooling and heating system, shading and light-supplementary system, CO_2 enrichment system, culture facilities, fertigation and automatic control system. Crop cultivation techniques and related equipment are also necessary.

In a word, faced with so huge amount of knowledge and techniques greenhouse engineering and its production management are challengeable, which leads to the emerging of expert system for greenhouse production management.

The application of expert system on greenhouse production management has been emphasized by many researchers, especially on greenhouse cultivation and environment control. A decision analysis and expert system model was applied to the problem of individual nutrient selection for cucumber growth in a controlled environment (Fynn et al., 1994). A computer-aided decision-making expert system for greenhouse cucumber was developed, which included cultivation management, pest and disease diagnosis and prevention (Chen & Li, 2001). VEGES was developed for diagnosis of nutrient deficiency, pest and disease on greenhouse vegetable (Yialouris et al., 1997). The humidity and temperature of a laboratory scale greenhouse are controlled using a rule-based expert system (Türkay, 1994). Artificial neural network was adopted to determine the temperature setpoint for greenhouse tomato by data collection rather than growers' experiences. Compared with conventional expert system it has the advantage of short control time and higher accuracy (Seginer et al., 1996). An expert system based on optimal fuzzy control strategy fulfilled real-time temperature control by on-line adjustment of setpoint (Jacobson et al., 1989). GHMES was developed to carry out the real-time environment control based on crop model and cultivation management (Hu et al., 2006).

The chapter deals with expert system development and application for greenhouse vegetable production management, including general description of greenhouse production system, design on expert system for greenhouse production management, integration of environment control subsystem with the expert system, software fulfilment of the expert system and two application cases in greenhouse vegetable production practice.

2. Design on expert system for greenhouse production management

2.1 System functional structure

According to the analysis of greenhouse and its production process, the expert system is composed of four subsystems (in Fig. 2), which are cultivation techniques, consultation of pest/disease and nutrient deficiency, diagnosis of pest/disease and nutrient deficiency, and environment control decision. Under each subsystem, there are still several subsystems.
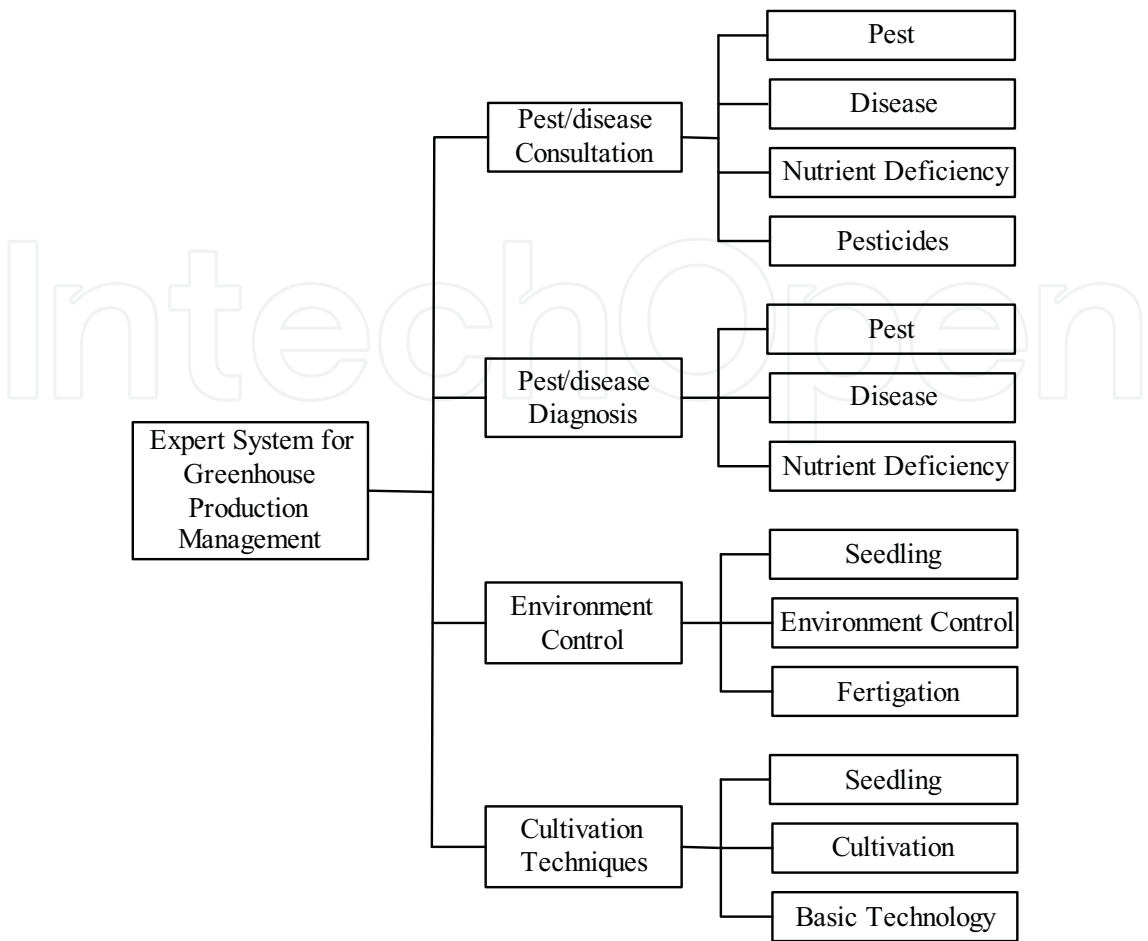
Fig. 2. System structure

2.2 System configuration

Modular design method is adopted to configurate the expert system and every independent module is combined by master module. Main modules of the expert system include inference diagnosis module, database management module, cosultation module, decision on environment control, text browsing module and help module. Correspondingly, system software structure is shown as Fig. 3.
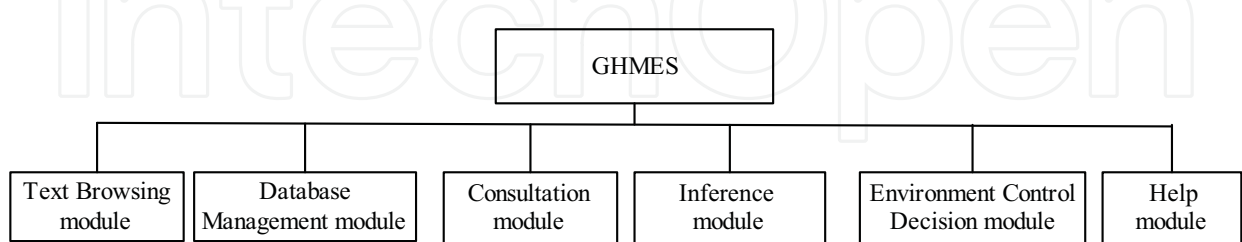

Fig. 3. System software structure

1. Inference and Diagnosis Module

   This is the core part of the expert sytem, which deals with the diagnosis of common pest/disease and nutrient deficiency for greenhouse crops. It can draw a diagnosis conclusion step by step and provide prevention and treantment mothed for user's reference.

2. Database Management Module
   The module is used for creating, editing and modifying knowledge and database. The known data, knowledge and rules of the expert system are also created, edited and modified through the module.
3. Text Browsing Module
   The module describes the botanical and physiological features of several typical greenhouse crops in text. Cultivation techniques and requirements of environment are also involved.
4. Consultation Module
   It includes both pest/disease and nutrient deficiency consultation modules. The module provides users with the type of pest/disease or nutrient deficiency and the expert system goes into the details such as symptom, occurrence regularity, prevention and treatment, and related pictures.
5. Decision of Environment Control Module
   There are two decision modes for greenhouse environment control, suiting for different occasions. One is on-line decision mode and the other is off-line decision mode. Under the on-line mode the expert system is integrated with the environment information collection system, based on which real-time environment control strategy can be worked out to complete the adjustment of greenhouse environment for good growth of crops. Under the off-line mode users input the present environment and crop information by hand and the expert system gives proper decision alternatives for user's reference.

3. Fulfillment of expert system for greenhouse production management

3.1 Database management

Among consultation module, cultivation techniques is called through text mode, and pest/disease, nutrient deficiency and chemicals are based on data dictionary, which result from large amount of searched basic data. For example, intuitive description of disease symptom and its pictures can be given by the system according to user's selection of different diseases.

Moreover, diagnosis module is also based on symptom, but the symptom is represented by particular knowledge. Here production rule knowledge representation based on relational database is adopted, and the knowledge is represented through database tables.

First, E-R model is established, which is an abstraction of real world. E-R model extracts common characteristics and neglects nonessential details, and describes the characteristics accurately using all kinds of concepts. There are three abstractions.
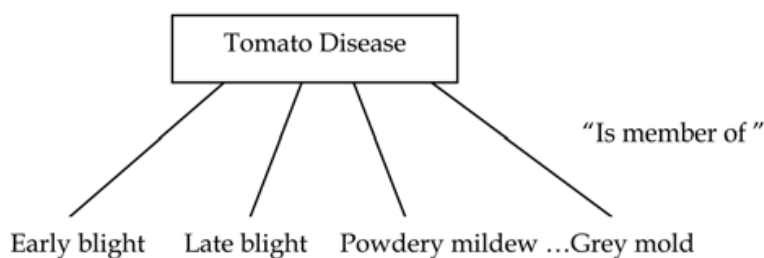

Fig. 4. Classification model

a. Classification defines a certain concept as a type of a group of objects, which have the common features and behaviours. Take tomato as an example, classification model is described in Fig. 4.
b. Aggregation is defined as a component part of a type. An entity is the aggregation of several attributes. In Fig. 5, the relationship between symptom and different parts is an aggregation.
c. Generalization is defined as a certain subset relationship between different types, which includes subtype and supertype. Generalization model is described in Fig. 6.
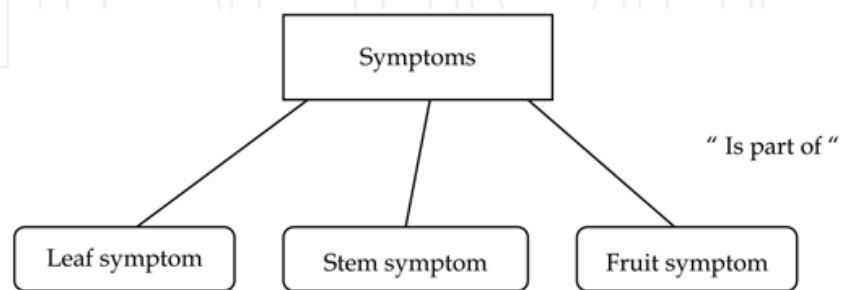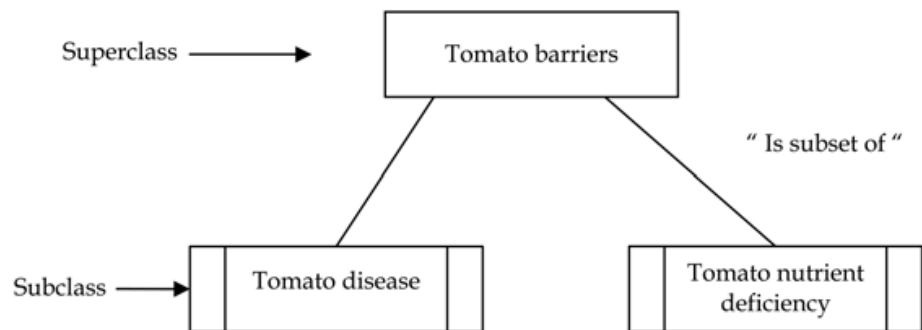
Fig. 5. Aggregation model

Fig. 6. Generalization model

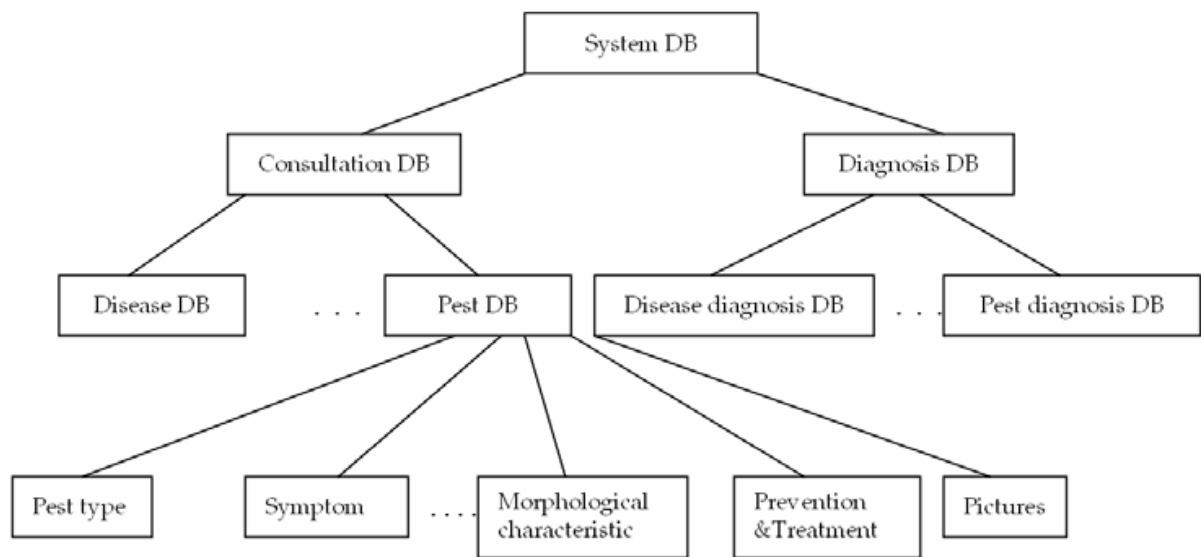Therefore, E-R model of the expert system is as follows in Fig. 7.

Fig. 7. E-R model

Then, E-R model is transformed into relational model, following the principle: one entity type is transformed into one relational schema, so entity attribute is relation attribute and entity code is relation code. The transformed data model is listed below.

Diseases:

Title	Symptom recognition	Occurrence regularity	Prevention/treatment	Pictures

Pests:

Title	Damage symptom	Morphological feature	Prevention/treatment	Pictures

Finally, the memory size of each data table field is determined, data and knowledge is recorded, and database is built. When using the database, maintenance of adding, deletion and updating is needed.

3.2 Design of knowledge base
3.2.1 Acquisition of knowledge
The source of knowledge is kinds of books, scientific reports and pictures. The reliability of the expert system depends on the quality of knowledge, so accuracy of fact description need to be guaranteed. The knowledge of greenhouse tomato growth barriers is briefly illustrated as follows.
1.   Symptom description with natural language
Tomato barrier symptom is described with simple natural language, and a piece of knowledge table is made. For example, as for the case of phosphorus deficiency, symptom and diagnosis is described as follows.

Crop title: Tomato
Symptom: older leaves etiolating with purple brown spots
Older leaves dropping off easily
Short small plant
Thin stem
Olive green leaves
Violet Leaf Venation on the back
Diagnosis: Phosphorus deficiency

Simple language helps to purify and order the knowledge, and forms a description and diagnosis table. Even though there is large number of tomato growth barriers, the most common symptoms and easily-recognized symptoms are listed in Table 1, with which a series of targets (conclusion) can be decided for every barrier. All described symptoms and important facts are linked to the targets, and then proper diagnosis rules are obtained.
2.   Rules of knowledge base
Representation of system symptom is based on the form of Object-Attribute-Value (OAV), which is suitable for developing any expert system based on rules. Most of the symptoms have one or several attributes and each attribute has at least one value. All the possible attributes and values of each symptom are collected and prepared.
Knowledge in description/diagnosis table is used to relate disease with its symptom. In the table the columns represent diagnosis and the rows represent symptom. Rules conformed to given column or row units are found out from rules of knowledge base. In addition, if a disease needs to be recognized by several rules, the attribute of the disease will appear in

Disease	Pest	Nutrient deficiency
Grey mold	Whitefly	Potassium
Late blight	Liriomyza sativae blanchard	Nitrogen
Leaf mold	Polyphagotarsonemus latus	Phosphorus
Spot blight	Spodoptera litura	Ferrite
Virus disease	Helicoverpa armigera	Calcium
Cercospora leaf spot		Magnesium
Blossom-end rot		Boron
Bacterial wilt		
Wilt		
Powdery mildew		
Sclerotinia sclerotiorum		

Table 1. Type of tomato diseases, pests and nutrient deficiency

several columns or rows of the table. When coding or decoding the table, rules are sorted out according to the etiopathology or inducement of the disease in Table 2. The rules of Table 2 are described as,

If   growth limited with light green/yellow older leaves then Nitrogen deficiency;

If   yellow or light yellow young leaves with green texture then Ferrite deficiency.

Symptom	Nutrient deficiency				
	N	N	Fe	Fe	……
Plant:					
Growth limited	X				
Wilting		X			
Color of older leaf:					
Light green	X				
Light yellow		X			
Green-purple					
Color of young leaf:					
Light yellow			X		
Green texture among nervations				X	
……………					

Table 2. Relation between tomato symptom and nutrient deficiency

3.2.2 Knowledge representation method

Knowledge base is essential to expert system and its structure and performance influence the accuracy and efficiency of problem solving. At the same time proper knowledge representation method may enhance the performance of knowledge base.

The knowledge within the expert system is represented and organized by the following types: descriptive knowledge, data knowledge and rule knowledge. Production knowledge representation based on database is used to strengthen the relation among knowledge and to reduce the number of production rules.

Rule base is the knowledge memory of specific field, and its representation is

$$\text{If } < \text{premise} > \quad \text{then } < \text{conclusion} > \quad \lambda$$

which means the reliability of conclusion is λ when premise comes into existence. $\lambda=1$ for accurate inference, and λ varies within $[0,1]$ for inaccurate inference. $<$ premise $>$ is the conjunction of facts and assertion.

Semantic model of the rules is expressed as Fig. 8.
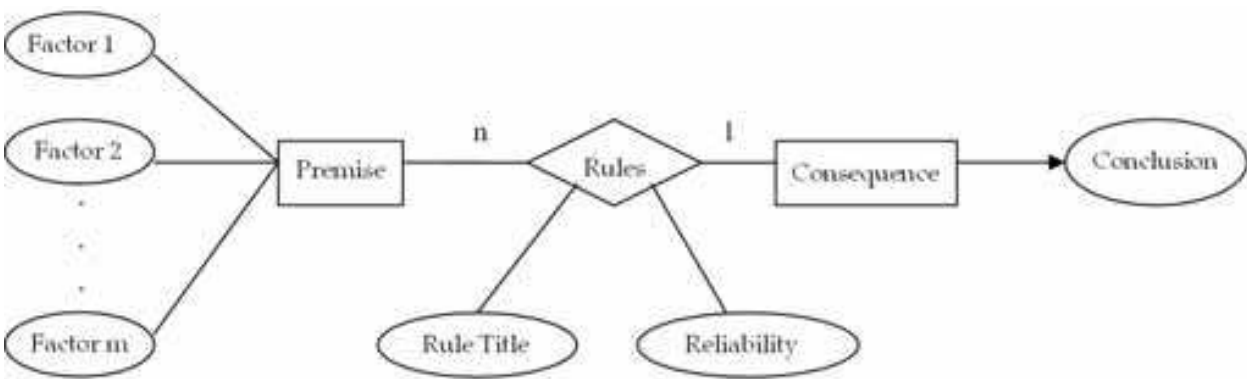
Fig. 8. Semantic model of the rules

Based on above semantic model, relational database and knowledge inference, rules are represented by relational database. Rule premise and conclusion are separated, and put into different database. Rules and related information is stored in rule premise base, and its structure is as follows.

Number of rules	Rule premise	Meet or not?

Rule conclusion and related information is stored in rule conclusion base, and its structure is as follows.

Number of rules	Rule conclusion	Number of premise	Number of auxiliary	contentment

Take a complete production rule as an example,

$$\text{if } < \text{premise 1} >, < \text{premise 2} >, < \text{premise 3} > \quad \text{then } < \text{conclusion} >$$

which means number of premise is three and conclusion can be made only when all the three premises meet the requirements.

3.2.3 Establishment of knowledge base

1.   Knowledge base of pest/disease diagnosis

Besides rule premise base and rule conclusion base, dictionary base is designed to make knowledge base management easier by storing premise, conclusion and code of the rule base. Its structure is dictionary (fact number, facts, known or not) Knowledge base is

essential to expert system and its structure and performance influence the accuracy and efficiency of problem solving. At the same time proper knowledge representation method may enhance the performance of knowledge base. The above three bases are structured through a table in Fig. 9.

2. Knowledge base of environment control decision

① Knowledge base of crop growth

It includes the requirement of growth on temperature, humidity and light intensity during different stages, which is acquired from expert's experiences, experiments and literature.

② Knowledge base of environment control

It covers the basic requirement on inside and outside environment control, priority of control parameter selection, actuator requirement under different climate, diagnosis and control strategy under abnormal situations. For example, roof window must be closed when it rains, or rolling screens must be closed if wind speed is too high.

③ Other auxiliary knowledge base

A. knowledge base of open-close of greenhouse

When the greenhouse actuators are in operation the open-close status of greenhouse is very important. For example, greenhouse must be closed when heating or CO_2 enrichment, or south and north rolling screens must be open and east and west rolling screens must be closed when cooling with sprinkling.

B. knowledge of environmental influence on crop growth

For example, higher temperature is needed to promote the growth of cucumber during the early growth stage, while too low humidity could cause its physiological barrier during the development stage.
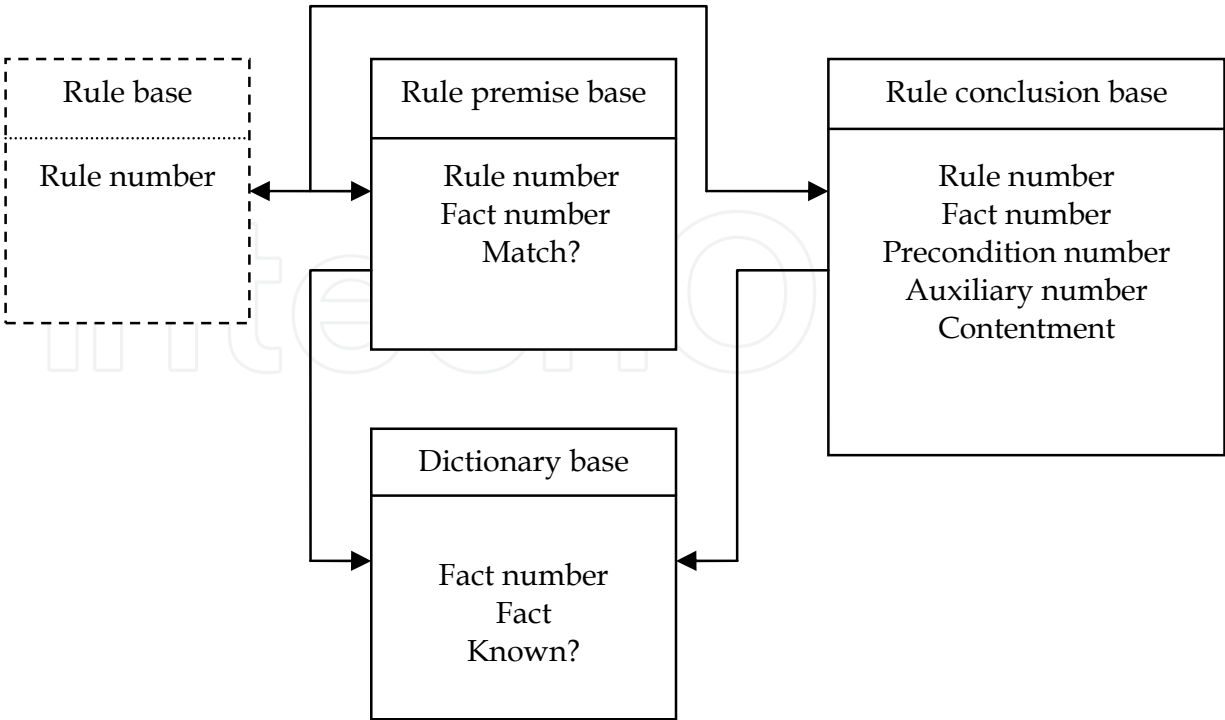

Fig. 9. Table-structured knowledge base

3.2.4 Organization of knowledge base

Knowledge base is organized by database management mechanism of SQL Server 2000, since knowledge is represented through relational database table. This kind of organization has the following advantages.

1. Knowledge base and inference engine are mutually independent, and the internal variation of organizational structure of knowledge base does not affect inference engine.
2. Expansion, maintenance and modification of knowledge are easily done with the help of database.
3. Rule files can be transformed into database files so that the normative and flexibility of knowledge representation are improved.
4. Multimedia knowledge representation is achieved through setting fields of picture, sound and animation in the conclusion base.

3.3 Design of inference engine

Inference engine may control and coordinate the whole expert system for greenhouse production management. The knowledge used for inference is accurate, and inference conclusion is definite.

3.3.1 Diagnosis of pest/disease and nutrient deficiency

Occurrence and development of pest/disease and nutrient deficiency are restricted by many factors, and here cropping system, growth season, temperature and humidity, and time are considered. Diagnosis of pest/disease and nutrient deficiency is based on symptom. The diagnostic flow chart is shown in Fig. 10.

The inference engine is built up with structured query language and forward inference is adopted. According to the given facts, rule premise database is searched to find out the matched record. The matching process is shown in Fig. 11.

For example, when users input information (pupae; oval shape), auxiliary number of rule is not reduced to 0 after inference. The inference conclusion is: greenhouse whitefly and liriomyza sativae blanchard, and detailed information of the two pests is listed. Final decision will be made by watching and judging the further features.
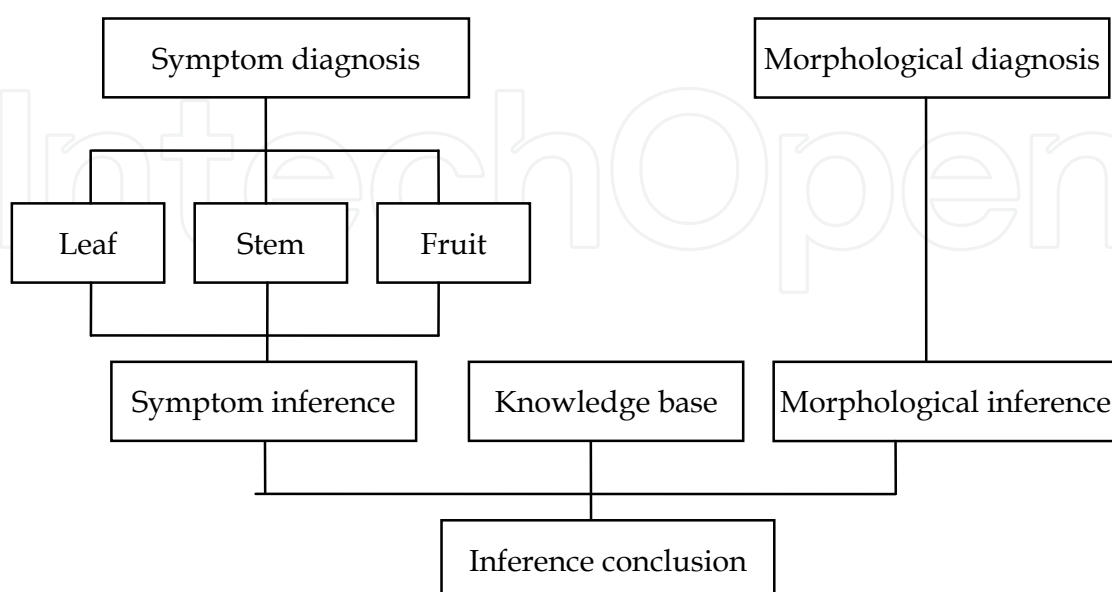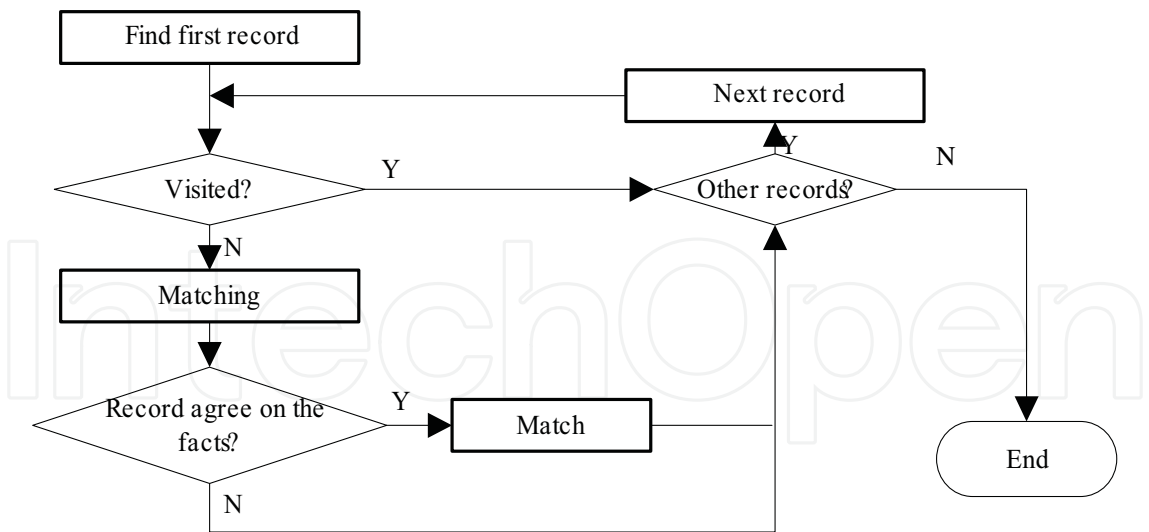

Fig. 10. Flow chart of diagnosis

Fig. 11. Flow chart of matching record

3.3.2 Environment control decision based on models

Different combinations of environment control actuators are listed in Table 3 (for summer) and Table 4 (for spring and autumn).

Combination number	Roof window	Rolling screen	Shading	Fan	Wet pad
1	0	0	0	0	0
2	1	0	0	0	0
3	1	1	0	0	0
4	1	1	1	0	0
5	1	1	1	1	0
6	1	1	1	1	1

Table 3. Combinations of environment control actuators for summer

Combination number	Half roof window	Roof window	Rolling screen	Shading	Fan
1	0	0	0	1	0
2	0	0	0	0	0
3	1	0	0	0	0
4	0	1	0	0	0
5	0	1	1	0	0
6	0	1	1	1	0
7	0	1	1	1	1

Table 4. Combinations of environment control actuators for spring and autumn

In Table 3 and Table 4, 1 stands for the status "Open" of the actuators, while 0 stands for the status "Closed" of the actuators.

The inference process is described as Fig. 12. First, users input environment information and the status of actuators manually or automatically through greenhouse environment information collection system. With photosynthetic model and knowledge of crop growth appropriate environment parameters can be figured out. At the same time current environment inside the greenhouse is judged to make sure it conforms to the proper range. Then keep the current status of the actuators. Otherwise, inference of environment control decision must be done in order to output the optimal environment control decision for users' reference.
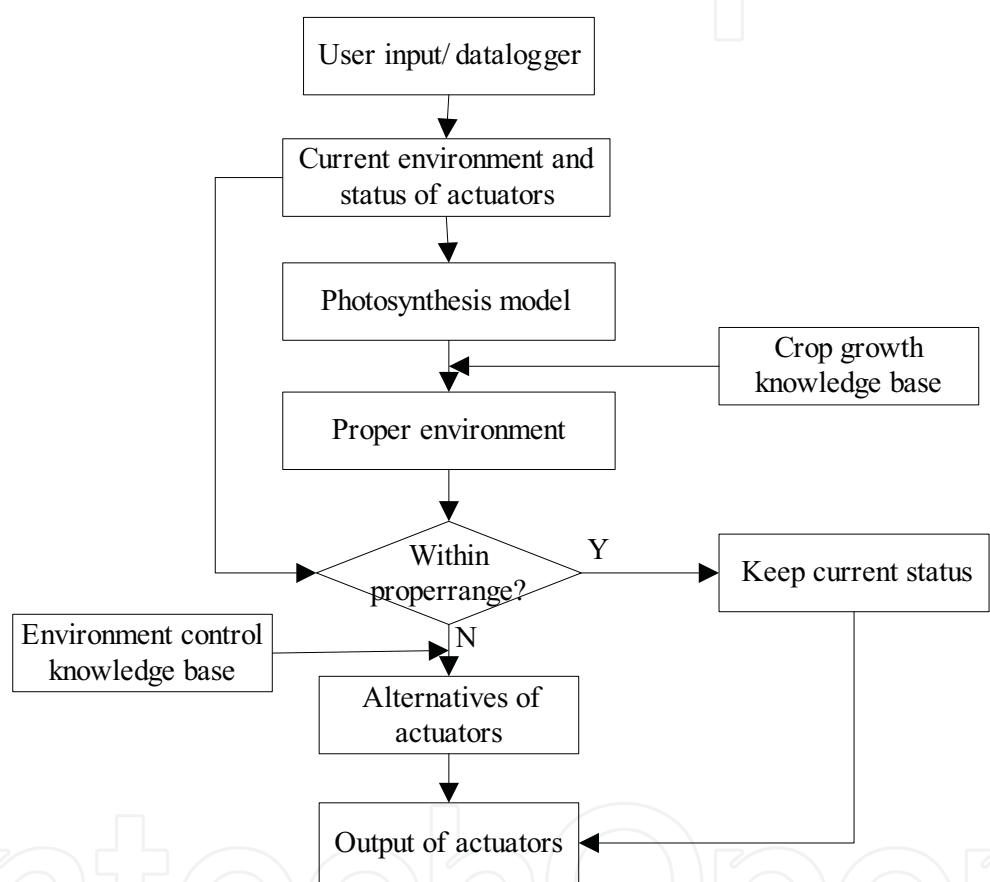
Fig. 12. Inference process of environment control decision based on models

4. Integration of environment information collection with expert system

To integrate obtained models and knowledge, especially current environment and crop information with greenhouse management expert system for vegetables and make better decisions, real-time environment information collection system is indispensable.

4.1 Overall design of environment information collection system
As a sub-system of greenhouse management system, environment information collection system provides expert system with real-time environment information and help to make proper environment control decisions.

4.1.1 Design requirements

The sub-system can collect environment information inside and outside greenhouses independently. All the information is stored in database, and can be used for greenhouse management expert system. The climatic parameters include temperature, relative humidity, light intensity and data of CO_2 concentration wind speed, wind direction and rainfall can also be collected by reserved extensible channels and interfaces for future purpose.

The system needs separate monitoring and unified management

4.1.2 System functions

For greenhouse environment control, single chip microcomputer receives climatic data from kinds of sensors, carries out logical operation and judgement with expert system, and then makes control decisions to adjust greenhouse environment. Meanwhile, it can help growers to analyze history dada and mine good management strategies. The specific functions are listed as follows:

Real-time monitoring greenhouse environment;

Updating the environment information database for expert system;

Information output and display with text, graph table or printout;

Alarming in case of extreme occasions or crop stress.

4.1.3 System configuration

Environment information collection system consists of sensors, data collection module and monitoring software. System configuration is shown in Fig. 13.

Each of the sensors is connected with data collection modules to obtain environment parameters inside and outside greenhouses. All data collection modules communicate with monitoring system (PC) through RS232/485 converter. Monitoring software is developed with configuration software, which is easily customized and interactive.
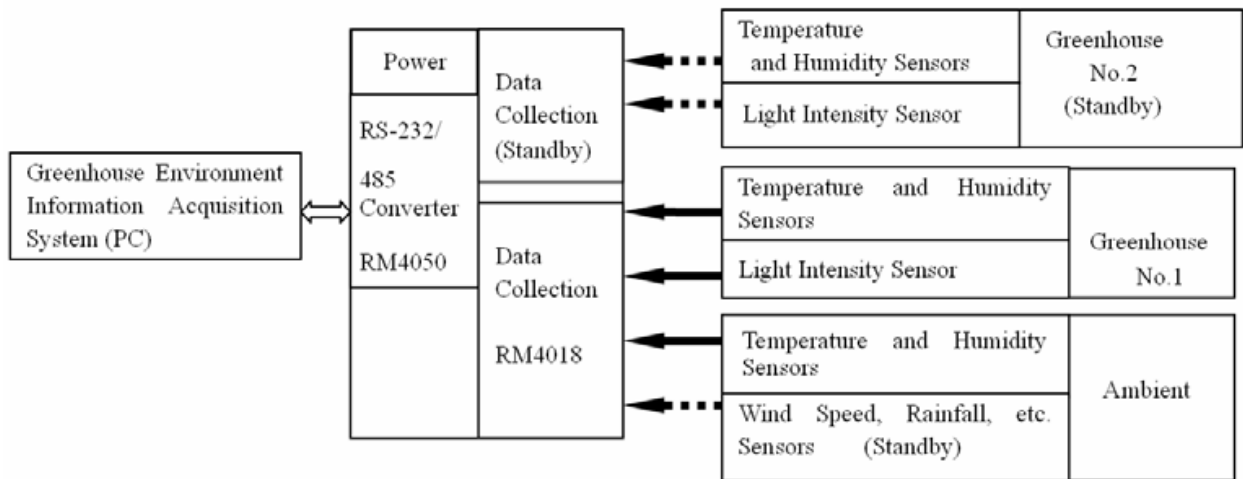
Fig. 13. Configuration of greenhouse environment information collection system

4.2 System hardware design

Selected sensors are used to measure temperature, relative humidity and light intensity. Integrated temperature and humidity sensor LT/W/S and light intensity sensor LT/G

adopt advanced circuit module to transmit signals, and output standard voltage and current, which can be switched by jumping lines. Specification of sensors is shown in Table 5. 8 channels can be linked to data collection module RM4018 and communicate with monitoring computer through the interface of RS485. RM4018 adopts MCU of AT89C2051, 12-bit A/D chip ADS7822 and multiplexer chip MPC508. Photoelectric isolation is used to enhance anti-jamming.

Sensor type	Range	Output	Accuracy
LT/W/S Temperature Humidity	-20~80°C 0~100%	0~20 mA 4~20 mA 0~5 V	±0.5°C ±3%
LT/G	0~100KLux	0~10 V	±3%

Table 5. Specifications of sensors

Module RM4050 adopts the techniques of photoelectric isolation and auto reversion to gain high reliability. System supply voltage and current is DC24V/2A and plastic case is self-made.

4.2 System software design

The software of greenhouse environment information acquisition system is developed on the platform of configuration software PCAuto3.1, which is a kind of special software for data collection and process control. PCAuto3.1 has flexible configuration not programming mode and can provide customers with friendly interface and easy operation.

Configuration software consists of project manager, development system, interface running system, real-time database, I/O driver, network communication program, serial communication program, dialing communication program and web server program.

The software of greenhouse environment information acquisition system includes real-time display, text and graph output, database management and system parameters setting. The main window is shown in Fig. 14.

The database of the software is called by the model base and environment control system, and then control decision can be made based on it.

First, database files of ACCESS is created, entitled data.mdb. Then the database form is correlated with configuration software form by the command of dynamic link library---SQLCreateTable. And one record of environment information is inserted by the command of dynamic link library---SQLInsert.

Finally, expert system directly calls real-time ACCESS database files to be processed for making control decisions.

4.3 System implementation

According to measuring requirement, sensors were put on proper locations and connected with the data collection modules. And the data collection modules were connected with a computer in which monitoring and control software had been installed

The system automatically recorded environment information at a certain interval and was put into expert system by the ACCESS database files. The system ran for 20 days with no software or hardware failures and successfully supported greenhouse management system with proper decision-making.
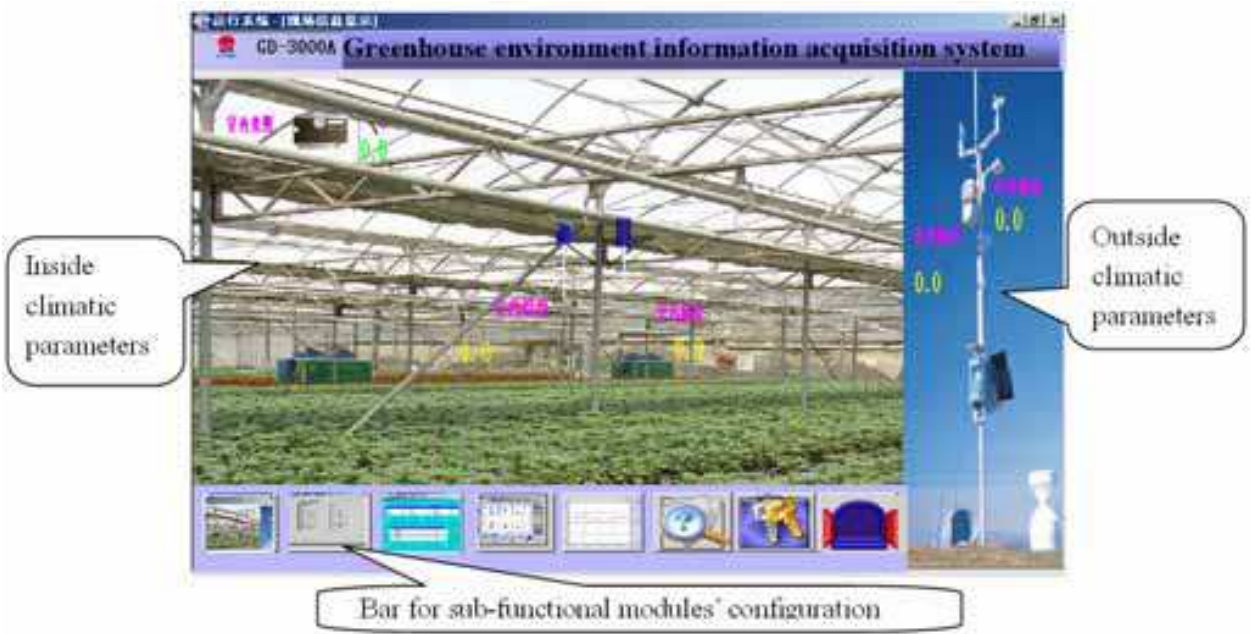
Fig. 14. Main window of the system software

5. Application examples of expert system

The operation of the expert system is simple and easy through menu-driven mode. Given functions include,

1. Consultation of basic cultivation information, dealing with botanical characteristics, requirements of growth environment and cultivation techniques during each growth stage.
2. Consultation of frequent pest/disease and nutrient deficiency symptom in greenhouses and chemicals for prevention and treatment.
3. Diagnosis and recognition of pest/disease and nutrient deficiency.
4. Decision on greenhouse environment control for on/off-line operation mode.

Fig. 15 shows the main interface of the expert system, consisting of title bar, menu bar and shortcut bar. Users can select corresponding functions by clicking them.
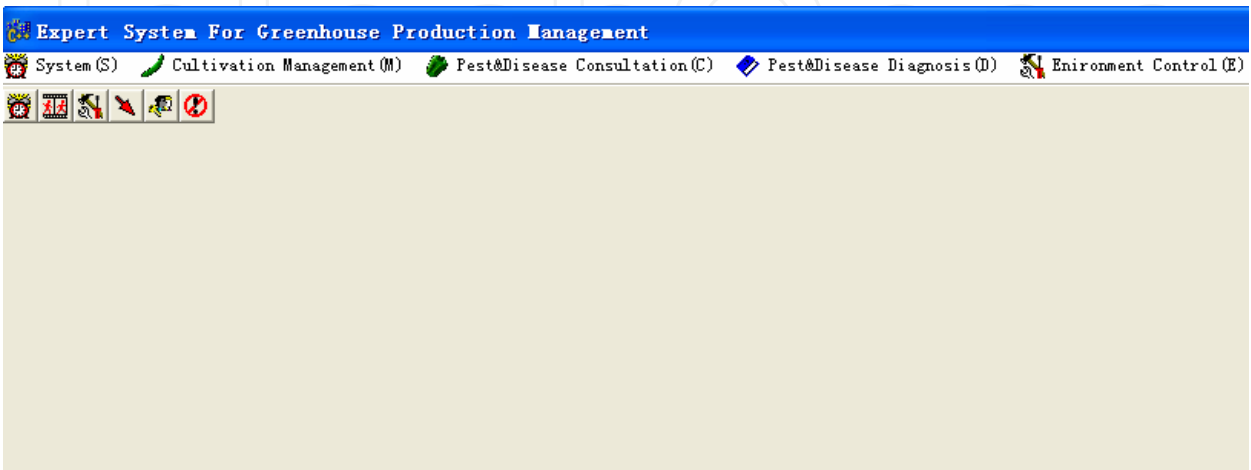
Fig. 15. Main interface of the expert system

5.1 Example of disease diagnosis

The general process of diagnosis is briefly described through tomato diseases. Fig. 16 is one of the subforms for diagnosis of tomato diseases. Tomato diseases are diagnosed by their damage symptoms, which have much difference according different growing parts such as leaves, stems and fruits. Users observe the tomato plant on site carefully, and then choose corresponding parts suffering potential diseases in the expert systen. Finally the diseases and their prevetion/treatment motheds are inferred by the expert system.

Fig. 16. Interface diagnosis for tomato diseases

Fig. 17, symptom selection dialogue box, will come out when clicking on "Leaf", affected position, in Fig. 16. Then all the disease symptoms related to tomato leaf will appeare in the list box of "selected knowledge or data". After proper selection the knowledge or data will be put into the list box of "selected inference knowledge". Here we choose three pieces of knowledge: "water-stain diseased spots, V-shape extended inwards from leaf edge", "drab or tawny spots" and "with grey mold layer", and save it as a database file.
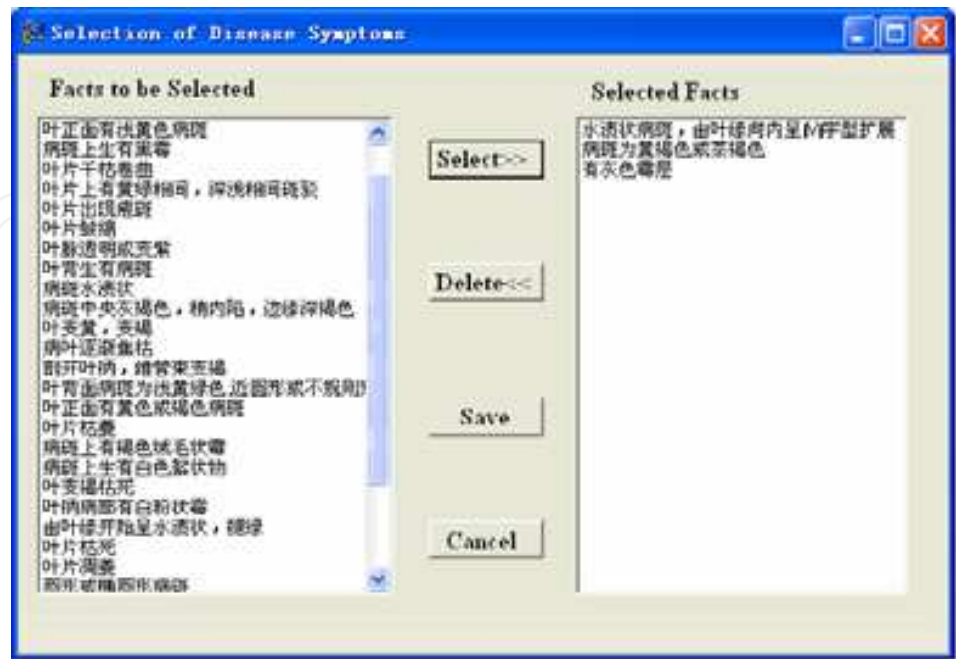
Fig. 17. Dialogue box of leaf symptom selection

For the fruit part, the operation is the same as the leaf part (see Fig. 18). At the same time another database file is created.

Fig. 18. Dialogue box of fruit symptom selection

After the above two-step selection, click the botton "Inferring" and the conclusion will be made in Fig. 19 by calling the knowledge base of disease diagnosis. The inference result shows that the tomato plant suffers grey mold, whose detailed information is listed in Fig. 19.

Fig. 19. Diagnosis result of tomato diseases

If only insufficient information is input, several inference conclusions may be obtained for user's reference and selection.

5.2 Example of greenhouse environment control decision
5.2.1 On-line decision

When users choose on-line decision mode the system collects environmental information inside and outside the greenhouse automatically. Fig. 20 shows both inside and outside environment parameters, including temperature, humidity and light intensity. The information is updated every a certain period. The current status of each environment controlling actuator is also shown. According to the specific crops cultivated in greenhouse, optimal environment conditions, irrigation span and recommended actuating alternatives will be decided through the expert system, wihich is shown in Fig. 21.

Fig. 20. Information output of greenhouse environment and actuator status

Fig. 21. On-line decision result

5.2.2 Off-line decision

Manual decision is carried out when users input the information of greenhouse environment and actuator status by hand, not through the collection system of environment information. Users may estimate and input light intensity at five levels due to no radiometer available (see Fig. 22). Base on above information off-line decision could be made in Fig. 23.
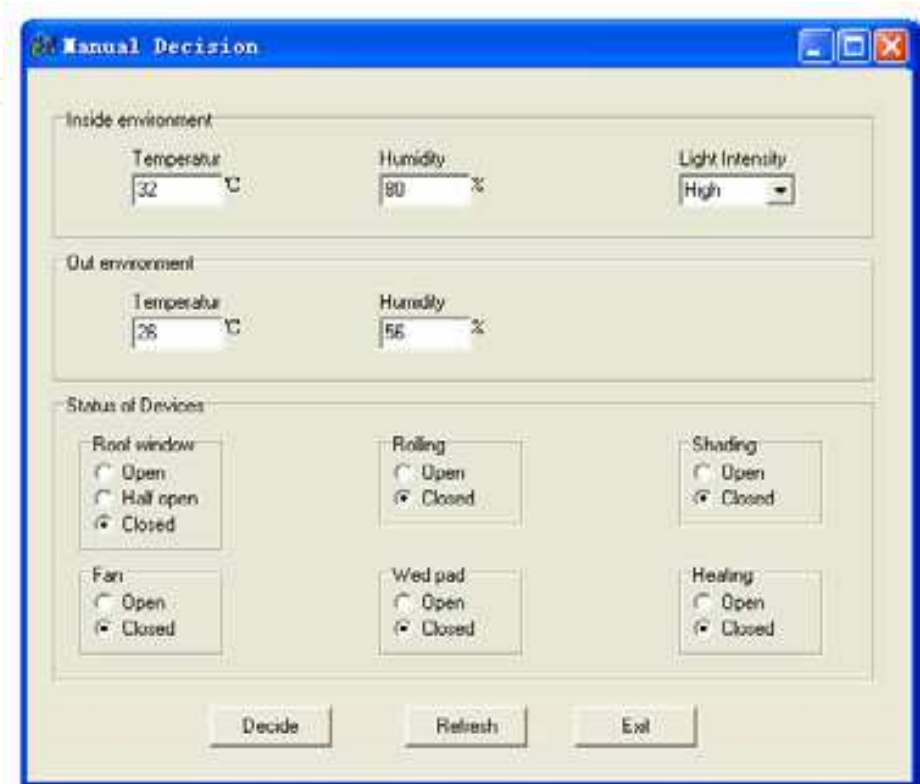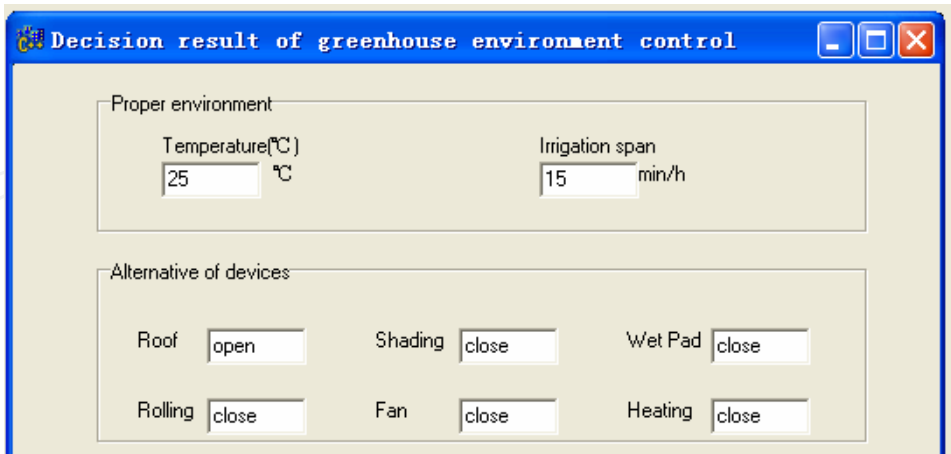

Fig. 22. Manual decision

Fig. 23. Off-line decision result

6. Acknowledgements

diagnosis module. The research was also funded by China and Jiangsu Provincial government (Project grant No. 2006BAD11A10, 30771259 and 08KJA21001).

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Expert Systems

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Expert systems represent a branch of artificial intelligence aiming to take the experience of human specialists and transfer it to a computer system. The knowledge is stored in the computer, which by an execution system (inference engine) is reasoning and derives specific conclusions for the problem. The purpose of expert systems is to help and support user's reasoning but not by replacing human judgement. In fact, expert systems offer to the inexperienced user a solution when human experts are not available. This book has 18 chapters and explains that the expert systems are products of artificial intelligence, branch of computer science that seeks to develop intelligent programs. What is remarkable for expert systems is the applicability area and solving of different issues in many fields of architecture, archeology, commerce, trade, education, medicine to engineering systems, production of goods and control/diagnosis problems in many industrial branches.

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