DDES: Dyeing Diagnostic Expert System for the Textile Coloration

Mostafa Goodarz, Mohammad Amani Tehran, Reza Mohammad Ali Malek, Firoozmehr Mazaheri and Taraneh Shenasa

Abstract—**Textile dyeing is a complicated process, so that quality of its final product is affected by the seemingly countless variables. As a consequence, diagnosing problems in this process is a very complex task. Troubleshooting process has been conventionally performed by human experts and the use of intelligence systems has been identified as a novel potential technology. Expert systems are computer systems that emulate and duplicate the behavior of experts for solving problems within a specific domain. Similar to a human expert, they can reason logically, make decisions and explain their conclusions. This paper reports on the development and evaluation of a dyeing diagnostic expert system (DDES) in the areas of cotton and polyester/cotton textiles and also compares construction methodologies of this system with the recently developed diagnostic expert systems in the field of textile coloration. The results reveal that the developed system can assist dyeing diagnosticians and other users by following an intelligent diagnostic method. It finds an optimal choice for handling human experts. Besides, it proposes an effective approach for integrating multiple experts' opinions or sorting experts' responses.**

Key words: Diagnostic expert system, textile, coloration, dyeing, defect

I. INTRODUCTION

Dyeing is one of the last operations in textile processes. This process generally can be represented by the scheme in Figure 1, in which the characterizing parameters of undyed materials are considered as input variables and the conditions that carry the dyeing operation as process variables. Thus, numerous variables affect the features of the end product (dyed fabric) as output variables in the dyeing process. Several criteria, such as shade consistency, levelness, color fastness and appearance as well as the visual appearance of final product are usually used for the evaluation of the degree of successes of dyeing [1].

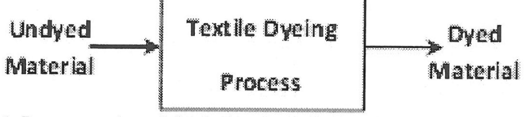

Fig. 1. Representation of the dyeing process.

However, the occurrence of faulty symptoms is very probable in dyeing procedures. Not only most faulty symptoms of dyeing causes in dyeing process, but also several unseen defects in the pre-dyeing processes may cause to these symptoms. Hence, each single faulty symptom should be traced to various sources such as fiber, water, spinning, fabric manufacturing, preparation, dyeing and human errors or any combination thereof [1-3]. Therefore, to obtain a desired result, an expert system should be taken several parameters into account that most of them are subjective assessments. For these reasons, troubleshooting problems in textile dyeing is complicated and has been carried out only by human experts.

Obviously, human experts are scarce and expensive and also would not be readily available in necessary situations [4]. During the recent decades, the knowledge acquisition techniques have found great progress in different applications by capturing and preserving of knowledge or expertise of experts and employ them in proper applications and have been known as computerized expert system [5]. Such techniques, for example, are capable of solving different dyeing problems.

In this paper, the development and evaluation of a dyeing diagnostic expert system (DDES) for assisting in the diagnosing of cotton and polyester/cotton dyeing defects is described. The system is also compared with the recently developed diagnostic expert systems in the field of textile dyeing.

II. RELATED WORKS

The use of computers in the coloration and textile industry dates back to 1960s. A significant number of papers have been published describing the applications of computer control in various fields of textile processing [6]. The implementation of artificial intelligence actively expert systems in the textile area back to the late 1980s. Textile applications of expert systems were introduced by Ruettiger, Demers, Curiskis and Grant over these years. However, there were also other researchers encouraged the textile manufacturing towards expert systems. So, the application of expert systems in textile industries has been continued until the recent years. Generally, the applications of expert systems have been tried in a wide variety of textile industry particularly in dyeing section. The chronology of expert systems within the scope of textile dyeing is illustrated in Figure 2 [7].

OPTIMIST and WOOLY were the pioneers of expert systems in the textile coloration even throughout the textile industry. OPTIMIST was developed by BASF (Rüttiger) to

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optimize the cheese and cone dyeing process [8]. WOOLY was the first expert system for analyzing of commercial textile dyeing that was presented by Sandoz [9]. This system is used for determination of dyeing recipes for wool and polyamide/wool articles. WOOLY could elicit the fastness requirements for a wide range of standard tests relative to type of article and machine and recommends details such as the processing route, dyeing methods, suitable dyes. The system is capable of being interfaced with a color matching system [9]. IGCSE expert system was reported by Gailey for the application of dyeing theories which covers all groups of dye/fiber as well as several solvent systems [10]. BAFAREX developed by BASF (Lange and *et al.*), was employed for the determination of dyeing recipes for cotton and polyester/cotton articles, using vat and disperse dyes [11]. Smartmatch was settled by Datacolour International for color matching goals and determining wool dyeing recipe [12]. Datawin is a dyeing control system developed by Viviani [13]. BATEM is an expert system that introduced by Convert and *et al.* which developed for the determination of dyeing recipes by considering type of article and machinery, employed dyes and color fastness requirements [14]. Calopoca was presented for color matching aims by Ciba (Herman) [15] and designed as an expert system for optimizing lab-to-bulk reproducibility purposes by Raeve and et al. [16]. An expert system was developed by the China Textile Institute for polyester exhaust dyeing [17]. Mizuno and Itoh designed an expert system for fiber-dyeing recipes [18]. Lee and Lin provided a recipe optimization expert system for the China Textile Institute [19]. The system is applicable for dyeing of different types of cotton fabric with reactive dyes and provides the quantified compatibility index for different mixtures of reactive dyes and suggests the optimal recipe in different dyeing conditions [19]. Shamey *et al.* reported an expert system for yarn dyeing. In this system, the commonness technique was implemented for sorting possible causes [20].

A diagnostic expert system named DEXPERT was constructed by the Shamey and his colleagues at North Carolina State University (NCSU) for the coloration of cotton. The required knowledge of the system was acquired from four expert dyers working in different part of the world (USA, UK, Pakistan and India). The configurations of "primary and secondary experts" and "individual experts" were used to handle the expert. It has been also used voting (based on certainty factors using an electronic survey software) to integrate multiple experts' opinions. By this method, the experts' responses on the possible causes were sorted. Accordingly, one of the experts was used as a primary expert whiles others were considered as secondary experts. Similarly, the certainty factors assigned by individual experts were averaged out to obtain a single number for each possible reason of a problem. In this system, classification and certainty factors were used as two main methods for sorting possible cause. The knowledge was represented in the form of rules. The tool used for developing this system was wxFuzzyCLIPS ver: 1.64 shell. In order to investigate the cause of a defect in a dyed cotton cloth in this system, the user first selects defect category, dye type and process method from presented lists, and then clicks the diagnosis button. Next, the system prompts to ask more questions about defect type until finally give suitable causes and recommendations to user [21, 22]. DEXPERT-P was developed by the Shim and his supervisors based on DEXPERT for troubleshooting issues in the coloration of polyester fibers. Knowledge of the system acquired from different literatures and fourteen expert dyers [23].

Recently, DDES was developed by the authors of this article as a troubleshooting system for the coloration of textiles at Amirkabir University of Technology (AUT). The system was described in details in Ref [24]. The system primarily was designed to diagnose defects that occur during the dyeing process of cotton. System is helpful for assisting expert dyers in the diagnosing of cotton dyeing as well as the training of non-expert dyers and students. DESS seems more successful than DEXPERT based on its training performance that provides some useful documents on the source of causes from the last to first steps [24]. DDES has a modular structure, and its designers in AUT are extending this system to promote the system to a fully comprehensive troubleshooting system which encompasses all common dye-fiber combinations. Accordingly, DDES was extended by the authors for troubleshooting possible problems in the coloration of polyester/cotton blends materials [25].

III. Development of DDES System

The architecture of the developed expert system is illustrated in Figure 3. As shown in this figure, the system comprises five elements, namely the knowledge base, the inference engine, the interactive user interface, the knowledge acquisition module and the explanation facility.

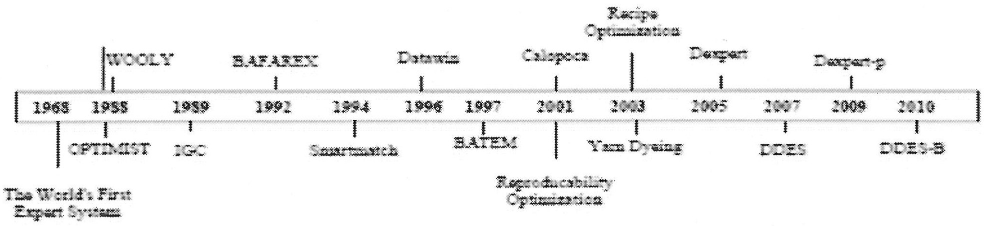

Fig. 2. Chronology of expert systems in the textile coloration.

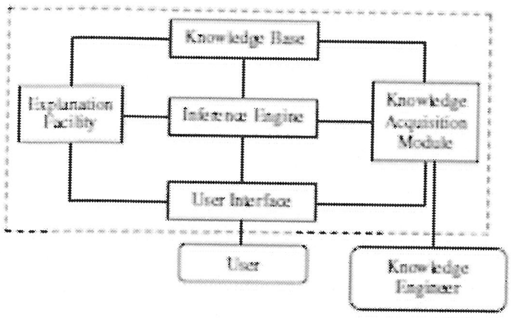

Fig. 3. The structure of DDES System.

For developing the system, it is important to adopt a systematic approach from the identification of the problem domain, through the construction of the knowledge base and eventually to the implementation and validation of the system [26]. The hierarchical stages of developing DDES system is shown in Figure 4.

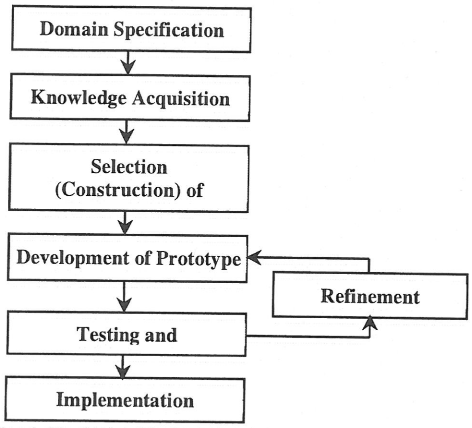

Fig. 4. The hierarchical stages of developing DDES system.

We have identified the problem domain as one of the key factors that determines the quality of an expert system project [27]. So, problem domain in the beginning of project has been specified. The scope of this system's domain includes diagnosing visual defects on cotton and polyester/cotton fabrics dyed with reactive, direct, vat, sulphur, azoic and disperse dyes in commonly continuous, semi-continuous and batch-wise processes. The system is designed in a manner to present the defect categories and definitions as well as the possible causes. In this way, the system designers will be able to improve the system with other common dye-fiber combinations.

However, there are also other important determinants of the quality of an expert system, consist of knowledge engineer, domain experts, and knowledge acquisition and representation methods [28]. Figure 5 shows the mechanism used for developing DDES system. The role of knowledge engineer is the most significant. The knowledge engineer acts as the intermediary between the domain experts and computer who acquires domain-specific knowledge from domain experts and after organizing, constructs the expert system using the development tool. The successful development tool (TES shell) is designed by an expert programmer with near cooperation of knowledge engineer; this shell can be helpful for developing diagnostic expert system in other fields of the textile. The knowledge engineer takes into account the interface that tried to be enough user-friendly, so that the end user will be comfortable consulting with the system to solve problems. The domain experts and users also test and evaluate the expert system. Knowledge engineer initially considers feedbacks elicited from them for designing the expert system.

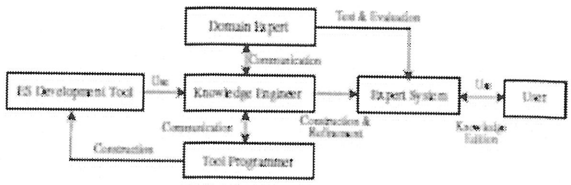

Fig. 5. The mechanism used for developing DDES system.

IV. KNOWLEDGE ACQUISITION FROM MULTIPLE EXPERTS

The most human experts, though starting off in their professions with a set of structured information and rules which gain through formal learning involve education in the university and attending training programs, seminars and other activities, then learn to do their job through a combination of formal and experiential knowledge and offer the right answer by using heuristics solutions (e.g., experiences, judgments, opinions, intuition, predictions). In this way, they may have followed a logical path, but mentally they may have skipped some steps along the way to get there. This is because, during the reasoning of an expert in dyeing, many variables are considered, and most of these variables are subjective and very difficult to express. However, the success of an expert system depends on the amount of its knowledge and its qualities. Therefore, there are high demands on knowledge engineer skills.

In many cases, expertise is not resident in the knowledge of a single domain expert. In fact, the multiple experts should be used to provide the mix of knowledge that is required in a complex structure, such as troubleshooting in textile dyeing and provide coverage for the many problems and solutions. However, using multiple experts for empowering the system knowledge is more complicated than single experts since it increases the stress of knowledge engineer. The problem originates from the fact that experts may disagree on the use of same concepts and vocabulary and such disagreement may be tacitly causing confusion.

Accordingly, knowledge acquisition from experts is the first and most difficult task in the development of an expert system. The mentioned problems can be relieved by the appropriate management of the knowledge acquisition process. The acquisition of knowledge includes extracting, analyzing, and organizing knowledge that human experts use when solving a specific problem and then representing this knowledge in a computer program.

Fortunately, this field has drawn great attention from researchers and numerous methods have been presented

[29-35]. At first glance, knowledge engineers take account of several configurations for using multiple experts. These configurations include "simultaneous experts", "individual experts" and "primary and secondary experts". In the case of simultaneous experts, knowledge engineer receives the knowledge from multiple experts simultaneously and then gains agree-upon solutions. This approach is an ideal method, but requires a long time period because of existing contentious issues and conflicting opinions. In the case of individual experts, knowledge engineer gathers the knowledge from multiple experts independently and then analyzes the best solutions. This approach does not require the experts to meet face-to-face and knowledge engineer might interact with experts by mail, email and other communication facilities. In the case of primary and secondary experts, knowledge engineer initially consults the primary expert for guidance in domain familiarization, providing first version of knowledge, refinement of knowledge acquisition plans, and identification of potential secondary experts, and then handles secondary experts for getting more knowledge. A combination of primary and secondary experts and one of other configurations is the optimal choice for acquisition of diagnostic knowledge in textile dyeing.

However, the expert judgments of multiple experts differ and the conflicts should be solved to integrate the multiple experts' opinions and/or sort experts' responses. For this purpose, there are many group consensus methods such as normative group technique (based on subjective probability which is depending on expert's idea, opinion, experience, judgment and intuition, only in the configuration of simultaneous experts), voting (based on certainty factors "CF", commonness counts "CC" and relevant probabilities), Delphi method (based on obtaining a unanimous decision through consecutive questionnaires, only in the configuration of individual experts), brainstorming (based on extracting all possible ideas, only then discussing the merits and limitations of the ideas given and thereafter best decision will be made).

In this work, with respect to existence of willing and able triple experts and active contribution of one of the experts as knowledge engineer, the face-to-face knowledge acquisition sessions was used. To conduct this process successfully, the configurations of "primary and secondary experts" and "simultaneous experts" was used. Normative group technique was also employed to integrate multiple experts' opinions.

However, for handling three expert dyers as "primary and secondary experts", one of the experts was used as a primary expert (knowledge engineer) whiles others acted as secondary experts. It has been admitted that, the primary expert was continuously in contact with secondary experts. Thus, the primary expert gathered knowledge from various available sources such as reference books, journal papers, standards, case studies and the internet. Knowledge engineer also tripped to a big corporation and held a series of meetings with nine employees compromising senior operators/ foremen/ managers/ engineers at different sections of textile mills i.e. dye houses, preparation, fabric manufacturing and spinning sections. In this way, session's time scheduled to avoid interfering with employee's normal duties and the session were held in the manager's offices for demonstration of the importance of desired project. The knowledge engineer had to avoid using "high-level" defects terms that might confuse the employees without formal education. However, in initial sessions with each individual employee, different types of historical and existent problems were extracted and the next several sessions dealt with causes and remedies of problems in greater detail. Although the knowledge engineer conducted the questioning, but interview sessions never had a rigid format; if a subject arose during a conversation, the engineer would pursue it while the employee's mind was still focused on it. Afterwards, all of the collected information arranged in a suitable format by knowledge engineer to provide first version of knowledge. Then, this knowledge presented to secondary top experts for validation and completeness. This effort took more than eight months for one full-time textile chemistry engineer. Then, knowledge engineer conducted interview sessions between secondary top experts that all expert dyers attended in joint sessions and followed a normative group technique to obtain a unanimous opinion. In these sessions, after primary expert stated his idea and reasoning about a particular issue presented in first version of knowledge; the discussion began and continued until a unanimous decision was achieved by the experts on the best solution. The interviewing sessions were held approximately once a week over a period about one year.

Generally, in initial interview sessions, primary version of troubleshooting knowledge for cotton and polyester/cotton blend dyed materials were reviewed with the top experts and corrected as necessary. Then, the various methods of expert's decision making process upon diagnosing dyeing defects were determined. Finally, query serials were developed and accordingly in the next several sessions the knowledge base was planned.

Despite having expectations for dominating the more talkative or experienced expert within the conversation, but conducting sessions by knowledge engineer and forbearing and esteeming all experts leaded to enhancing synergy among experts. Furthermore, the unique benefit of using multiple experts was cross-checking problems or topics stated by one expert that previously had not mentioned by other experts, thus a more comprehensive coverage of the various types of problems was gained. However, this approach was faced with some problems. There were difficulties such as meeting time scheduling and also a little time consuming due to compromising opinion conflicts.

V. Design of Diagnostic Strategy

In order to diagnose a defect, the expert system begins with an observed or given faulty symptom. Probable causes are then identified as an unsorted list and test in order of their priorities from viewpoint of simplicity and minimum expense of time and energy. Design of such diagnostic strategies is critical in an expert system development. Thus, a step-by-step knowledge acquisition process has been planned for reducing complexity of designing the diagnostic strategies.

First of all, classification, chronology and subjective probability were selected as three main techniques for sorting the possible causes. It seems that it is first research that uses the combination of these techniques in area of dyeing expert systems. A comparison of several methodologies for sorting hypotheses was published by shamey and Hussain [36]. The presented techniques were consisting of chronology, classification, probability, certainty factors and commonness. A combination of more than one method is the optimal choice for developing a diagnostic expert system for textile coloration. Classification aims to classify a defect in some way to narrow down the possibilities that need to be checked. Chronology is based on a chronological order. In this method, the checking process starts with the last known processing step and continuous to first step (or first to last). Subjective probability is assigned subjectively by an expert, based on his/her experience in a number of troubleshooting mills.

In second step, possible origins of defects of dyed cotton and polyester/cotton fabrics divided to three following locations. Next, in each location, various possible defects and related causes and remedies was investigated. The effect of each defect on appearance of final product of dyeing was also determined.

(a) Prior to preparation processes involve fiber quality, yarn formation, fabric manufacturing,

(b) Preparation processes involve singeing, desizing, scouring, bleaching, mercerization, and

(c) Dyeing process with reactive, direct, vat, sulphur and azoic and disperse dyes in commonly continuous, semi-continuous, batch processes.

In third step, visual defects classified to four groups: (1) poor shade reproducibility (Off-shade dyeing), (2) unlevelness, (3) poor color fastness and (4) improper appearance. Then, each groups divided into relevant subgroups. The complete classification of defects is shown in Figure 6. Next, with respect to first step information, chronology of causes and relevant remedies in order of last (dyeing) process to first (prior to preparation) processes was captured for each defect.

The forth step is the most important, because clarifying the most probable cause(s) of a defect, stated in previous step, with minimum expense of time and energy is one of the prime aims in diagnosing process. The initial hypothesis generation is mainly based on the logic commonly used by dyers to detect and diagnose an observed defect. First of all, hypotheses are investigated to obtain the simplest possible cause; this means the cause that is cheapest to diagnose and correct. For instance, it is not unusual that a driver claims for a non-starting engine without observing an empty fuel tank. Then, if diagnose is not successful, they proceed for the most likely cause. These techniques are used as heuristic search path to locate the most probable cause. So, for diagnosing problems powerfully, the expert system designs so that can `think' logically like a human expert. Thus, the various methods of expert's decision making process upon diagnosing dyeing defects were determined and then search path of experts for solving all defects was put into a set of rules of the form If <symptom> Then <cause>. Next, the priorities has been identified for testing all possible causes in an optimum order, and accordingly query sets are developed.

VI. Reasoning Mechanism

The knowledge of DDES comes in the rules form. The rules benefit from If-Then structure and are manipulated by combination of the backward and forward chaining method.

Forward chaining supports what is called "data-driven" reasoning and works from LHS (the effects) to RHS (the symptom) of rules. Backward chaining supports goal-driven reasoning and works from RHS (the symptom) to the LHS (the causes) of rules [37].

Thus, DDES uses backward chaining for identifying the symptom from narrow-down defects categories and then utilizes forward chaining for reaching to the most possible causes and relevant remedies. Flowchart of the reasoning path of DDES is given in Figure 7. DDES inference follows a hierarchical tree-like format in a manner that the system prompts options from the top of the search tree to bottom of them and looks for a search level in the search tree at each step with regard to user responses to yes or no questions and finally receiving a result. Among this process, a number of factors (symptom class, process type, dye type, machinery type, etc.) have been taken into account in the selecting rules.

VII. Implementation of DDES

DDES is provided a user-friendly interface, so that it could be used by dyers who are not skilled computer users. This program has been designed by Visual basic language, and Microsoft access is used as knowledge base platform with if-then rule configuration. This expert system calls database using structured commands of SQL server. DDES runs on windows environment. This interactive program begins by asking the user a set of general questions about the user name, material code, material properties, dyeing setting, process type and dye classes. The inserted information by each user could be kept by the system. This facility makes user able to search the status and results of other previously symptoms recorded by former users. Then, the system allows the user to start diagnosing process. However, once the user selects a defect from categories of defects, he/she can initially requests its clear definition, and then reports defect to system to pursue the relevant causes and remedies. In this way, the system displays a series of query windows to user for testing hypotheses that the user should answer them by yes/no response. Depending on the responses, the system arrives at a justification of the hypothesis or selects a search branch where a new hypothesis is generated. At the end of

1- Poor Reproducibility (Off-shade dyeing)
1-1- Reproducibility Lab
1-2- Lab to bulk Reproducibility
1-3- Bulk Reproducibility
2- Unlevelness
2-1- Random Unlevelness
2-1-1- Cloudy dyeing
2-1-2- White or light coloured specks
2-1-3- Pale or off-shade areas
2-1-4- Skitterness
2-1-5- Frosting
2-2- Widthwise Unlevelness
2-2-1- Barriness
2-2-2- Listing (Side-center-side shading)
2-3- Lengthwise Unlevelness
2-3-1- Warp ways (streaks) or Stripiness
2-3-2- Tailing
2-3-4- Ending
2-3-5- Heavy colour
2-3-6- Crease break or Breakline
2-4- Back to face dyeing (Side to side dyeing)
2-5- Spot or Stain
2-5-1- Resist spot
2-5-2- Dye spot
2-5-3- Foam spot
2-5-4- Blotch or Oil spot
2-5-5- Dirt spot
2-5-6- Water spot
2-5-7- Coloured specks
2-5-8- Halo
2-5-9- Foreign matter or fiber
3- Poor colour Fastness
3-1- Poor wet fastness
3-2- Fading
3-3- Colour abrasion
4- Improper Appearance
4-1- Crease
4-2- Abrasion mark
4-3- Pilling
4-4- Physical damage
4-5- Poor lustre
4-6- Improper handle

Fig. 6. Classification of defects.

checking hypotheses and consultation, a window is displayed includes causes and relevant remedies for solving reported defect. Thus, in DDES, defects are solved by dialogues that take place between the user and system. The system is also equipped with an easy-to-use rule editor on menu bar which has four options including "Modify rules", "Modify defects", "Modify causes" and "Modify remedies". A window is appeared by choosing first option which through it can add a new rule or edit existing rule in the system. It is also possible to edit the system facts involved defects, causes and remedies by choosing other options.

VIII. Testing and Refinement of DDES

The knowledge acquisition team evaluated the prototype for functionality of the program and knowledge completeness during throughout development phases and refined them as necessary. This process was performed by triple expert dyers with different profiles. Expert A had a useful experience of managing in the textile dyeing industry. Expert B had experience as consultant in textile dyeing industry and also as a manager in a textile dyeing lab. Expert C was member of R&D staff at textile industries as well as several years experiences in one of the well-known international dyestuffs producer. The participation of expert C in troubleshooting and consulting position in textile industry was pronounced. Experts B and C are also members of academic staff at Amirkabir University of Technology in Tehran.

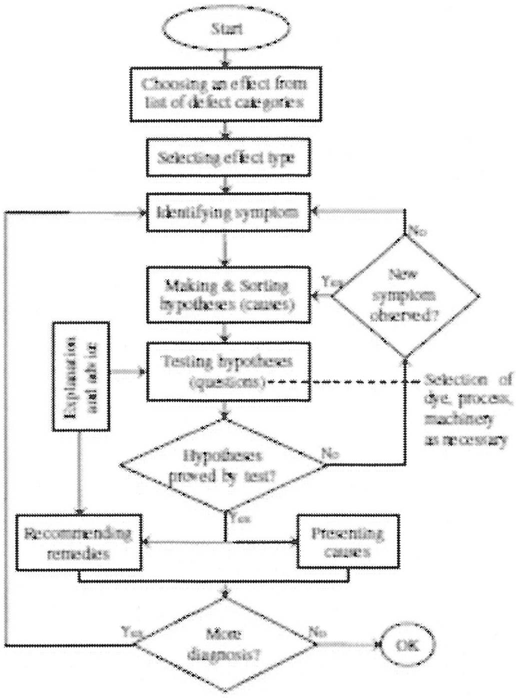

Fig. 7. Flowchart for the reasoning path of DDES.

A series of samples from the faulty dyeings were collected to provide actual faulty symptoms in the knowledge base of DDES expert system. These faulty symptoms were the real possible problems which may occur in production line of textile dyeing. These symptoms were introduced to the system and then evaluated the system results and refined as necessary.

Human experts usually take a set of specifications into account for the evaluation the system, which included:

Categories of defects are comprehensive;
Definitions of defects are clear and illustrative;
Follows logically an optimal sequence of questions;
Questions are clear and concise;
Recommendations are easily understood;
Contains questions/answers for all possible scenarios;
Recommendations are logical and accurate;
Selection of answers is complete.

At the end of project, in addition to mentioned experts, evaluating the system similarly was done by two experts that were different from those involved in the knowledge acquisition process. These experts were working at the cotton and polyester/cotton textile industry as dyeing manager. Finally, the system met the approval of all of experts.

Obviously, it is not possible to demonstrate all possible diagnostic results by experts in this paper. Considering all symptoms, rules and tests, can create a combinatorial large output. So, for the sake of demonstration, an actual diagnostic example which was run by one of the expert is described in the following paragraph.

The user inserted elementary data such as name, woven cotton fabric, vat dye, pad-dry-bake continuous process