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Development of A Diagnostic Expert System (FDD-Expert) for Woven Fabric Defects

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Abstract: A variety of computer aided techniques have been proposed to help solving diagnostic problems in different disciplines. Commonly known as expert systems, approaches, undertaking distinct formalisms for modelling domain knowledge, include: rule-based and frame-based systems or semantic and neural networks. Explanatory mechanisms are more easily implemented with rule-based systems and graphical models making these preferred solutions to the diagnostic problem. Since the pioneering work by Feigenbaum (DENDRAL, 1971) theory and utility of expert systems have progressively evolved, and accompanied by the appearance of various expert systems development tools. In textile industry, expert systems are generally used to increase production, improve quality and reduce costs.This paper describes Fabric Defect Diagnosing System (FDD-EXPERT), an expert system in the domain of fabric defects. Fabric defect is known as an undesirable fault in the fabric which deteriorates the quality fabric and makes it inferior. FDD-EXPERT contains 173 different defects based on TS471 ISO8498 Woven Fabric Description of defects with additional 47 defects. Defects depicted in this domain are classified based upon their similarity of appearance, multiple attributes relevant to effect upon visual quality and sources of defects. Possible reasons for each defect and remedial solutions are also included. A rule-based knowledge domain and interference engine is generated in PROLOG. User friendly interface of the system is developed through Visual Basic (VB.Net). It is a combination of logic and declarative programming. This diagnostic system may be utilised as problem solving and training tool by novice operators or as a supplementary knowledge for expert operators.

Keywords: Fabric defect, Diagnostic expert system, Prolog

Introduction

Expert systems have found broad acceptance in various technical, medical and social disciplines over the decades. They may be used in a wide area of applications to solve problems related to: Analyzing, Classification and Interpreting; Diagnosing and Debugging; Monitoring and Control; Design, Planning and Prediction; and Training and Instruction. Practical expert systems within each of these application areas do exist (Frenzel, 1988). An expert system is a knowledge-based system emulating expert thought to solve significant problems in a particular domain of expertise. It is a computer program which uses explicitly represented knowledge and computational inference techniques to imitate a human expert in a specific domain (Grimson and Patil, 1987).. Therefore, expert systems usually have two major components: a knowledge base and an inference strategy. The knowledge base incorporates a collection of facts and rules.

Failure diagnosis has become increasingly important for industrial automation and a variety of fault / defect detection. Therefore various diagnosis techniques have been developed for the diagnostic problem in technical

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processes. These techniques include model-based approaches, knowledge based approaches, qualitative simulation based approaches, neural network based approaches and classical multivariate statistical techniques..

In this paper, an expert system has been developed for diagnosing woven fabric defects. In general, textile materials are highly varied by nature, and the effect of variation or unevenness is likely to generate some faults or defects in manufacturing process. Consequently, occurrence of defects resulting from hundreds of different reasons are inevitable. The identification of a wide range of defects and solutions to eliminate them is very important as it directly relates to productivity and quality. The use of expert knowledge in this area for an expert system has been the focus of this work.

Review of Expert Systems for Fault Diagnoses

In the late 1960's to early 1970's, expert systems began to emerge as a branch of Artificial Intelligence. Domain specific knowledge was used as a basis for the development of the first intelligent systems in various domain. One of the best references for all the early systems was published Feigenbaum (1981). In the 1980's, expert systems emerged from the laboratories and developed commercial applications due to the powerful new software for expert systems development as well as the new possibilities of hardware . During the period 1985-1995 expert systems were very much popular topic in artificial intelligence developments due to the attention in knowledge management issue (Angeli, 2010). After 1995 expert system applications appeared to decline as stand-alone systems and their technology embedded in mainstream of information technology. New expert systems was set to combine symbolic with numerical information or with other artificial intelligence techniques to produce more effective systems.

The Expert System is one of the well-known reasoning techniques that is utilized in diagnosis applications domain. According to an MIT report by Scherer and White (1989), the first diagnostic expert systems for technical fault diagnosis were developed in the early 1970’s. Since then numerous systems have been built. Several researchers combine numerical with qualitative methods the last few years and various methodologies have been proposed for the combination of knowledge-based techniques. Surveys of early diagnostic expert systems for technical processes were provided byTzafestas (1986) and Scherer and White (1989) and by Liao (2005). Early diagnostic expert systems were rule based and used empirical reasoning whereas new model based expert systems use functional reasoning. The utilization of Expert systems for the supervisory systems used in the automatic control of the industrial processes are reviewed by Alexandra (1998). Some concepts related to the problem of supervision and diagnosis, as well as the functions and principles associated are also presented.

Diagnostic expert systems have also found application in network conditions. Web-based expert systems are based on traditional expert systems technology, rule-based and case based reasoning primarily (Kumar & Mishra, 2010). They incorporate client-server architectures and web browser-based interfaces (Grove 2000; Duan et al 2005).

The application of expert system in the field of textiles is also common to take advantage of knowledge-based computer programs in order to solve diversified and complicated problems based on human expertise. Development of expert systems in textile industry is focused on to increase production, improve quality and reduce costs. The common application purposes of the expert systems are:

- design or configuration of a textile product and clothing or a process
- diagnosing fabric, garment, machine or process faults
- quality detection in various processes

Examples of early expert systems which were developed for applications in the textile industry cover various operations such as diagnosing defects in the bleaching of cotton fabrics (Günther, 1989), predicting a wool dyeing recipe (Frei & Walliser, 1989 – 1991), finishing (Texperto) (Frei and Poppenwimmer 1992), pad-steam dyeing (Bafarex) (Lange et al, 1992), the colour matching process (Smart-Match) (Karamantscheva 1994; Datacolor International 1997), controlling the dyeing process (Viviani 1996).

An intelligent diagnosis system capable of tracing possible breakdown causes of fabric defects is applied to fabric inspection processing by Lin and his collegues (1995). In addition to the basic expert system, a diagnosis system developed using fuzzy set theory was also integrated. The system, using the Turbo C program, can act as an expert consultant for operators tracing the causes of breakdowns at any time, and the expert system, developed in an artificial intelligence language PROLOG, can provide the operator with a knowledge base for further consultation in fabric inspection. It was reported that, thanks to intelligent diagnosis system, even a new operator lacking expertise or skill in the weaving engineering field can still easily determine causes of fabric defects in a fraction of a second and then eliminate them. The results of experiments on various diagnostic cases was proved to be satisfactory by performance. This system was further developed by Lin (2009) by using a search mechanism based on genetic algorithm which can help find the correct solution (i.e., upper boundaries and lower ones) to the inverse fuzzy equation.

Dlodlo and colleagues (2007) developed a hybrid expert system architecture to support yarn fault diagnosis. The system has used a combination of rule-based and case-based techniques to achieve the diagnosis. Chung-Feng and his collegues (2014) published a work on diagnosing single or double fault conditions of significant process parameters based on the spinline tension signal in meltspinning process.

A review of applications of expert systems into various areas of coloration and textile industry has been presented by Goodarz and his collegues (2010). Shim (2009) has develop a knowledge-based diagnostic expert system to troubleshoot issues in the coloration of polyester materials as the most widely used synthetic fibre. The study was accomplished in four stages: selection of a suitable ES development tool, knowledge acquisition, design and development of appropriate modules and finally testing and evaluation of the system. An expert system for troubleshooting of faults encountered in ink jet printing of cotton substrates is developed by Kalav (2012). An analysis and selection of the most encountered faults in ink jet printing, the processes, which start with cotton production and end at fixation, are examined. Thirteen symptoms are selected as the most encountered problems in ink jet printing of cotton substrates. In addition, sixty-one causes are suggested as the possible causes of thirteen symptoms. The system is reported as a useful tool for troubleshooting of ink jet printing of the cotton substrates.

A hybrid intelligent classification model as a size recommendation expert system is proposed in a recent work Shahrabi, Hadavandi and Salehi 2013). Three stages for developing a hybrid intelligent classification system based on data clustering and probabilistic neural network (PNN) are proposed. In the first stage, the clustering algorithm is used for specifying the sizing chart. In the second, the resulting sizing chart is used as a reference for developing a new intelligent classification system by using a
PNN and the accuracy of the proposed model is evaluated by using the Iranian male's body type data set at the last stage. It is proved that experimental results show that the proposed model has a good accuracy and can be used as a size recommendation expert system to specify the right size for the customers.

A Case-Based Reasoning method was proposed in a recent study (Perez, et al. 2017 to complement the results of the finite element simulation, mathematical modelling and neural networks methods. The analysis of textile designs or structures includes the use of mathematical models to simulate the behaviour of the textile structures (yarns and fabrics). The Finite Element Method has largely facilitated the prediction of the behaviour of that textile structure under mechanical loads. Artificial Neural Networks for classification problems is claimed to be a very effective tool as a quick and accurate solution.

A recent work (Sawatwarakul, Joines, and Shamey, 2015) introduces the design and development of a diagnostic expert system for the dyeing of protein fibres. The system is designed to aid in the identification of root causes of problems with a view to enabling users to arrive quickly at remedial solutions. The performance of the system was reported as highly satisfactory. This diagnostic system is proposed to teach students an to be utilised by novice colourists as a problem-solving tool, and also to be employed as a supplementary knowledge resource by seasoned dyers.

Expert System Structure

The Expert System is a knowledge-based system that consists of two main modules: the knowledge base and the inference engine. It is an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution. Expert systems usually have a knowledge acquisition module and an explanation module as extra components. A typical expert system for fault recognition is shown in Figure 1.

A typical Expert System consists of three components: an inference engine, a knowledge base and a working memory. Declarative descriptions of expert-level information, necessary for problem solving, are stored in the knowledge base. The inference engine solves a problem by interpreting the domain knowledge stored in the knowledge base (Nabiyev, 2002). The inference engine also records the facts about the current problem in a special purpose workspace, called working memory. The working memory may also include modules for a natural language communication with the user, a reasoning explanation interface as well as an automated knowledge acquisition tool.

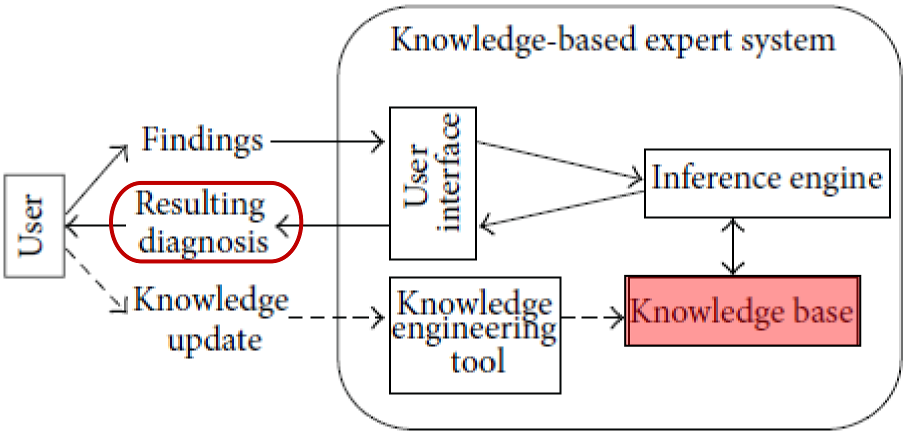

Figure 1. Basic structure and components of a diagnostic expert system

Expert systems approach undertaking distinct formalisms for modelling domain knowledge which includes rule-based and frame-based systems or semantic and neural networks. Rule-based programming is one of the most commonly used techniques for developing expert systems. A rule-based expert system consists of a set of rules that can be repeatedly applied to a collection of facts (Soe & Paing, 2008). The following concepts are essential to rule-based systems:
- Facts represent circumstances that describe a certain situation in the real world.
- Rules represent heuristics that define a set of actions to be executed in a given situation.

There is a basic distinction between derivations and production rules. Derivation rules have the form if <condition> then <conclusion>, whereas production rules conclusion, in derivation rules, is abstract: it consists of deriving logical consequences from certain conditions.

Explanatory mechanisms are more easily implemented with rule-based systems and graphical models making these preferred solutions to the diagnostic problem

Defects in Woven Fabrics

Textile manufacturing operations involve a series of processes towards to converting textile fibres into yarn, fabric, finished fabric and clothing. In consideration of huge variation in physical properties of textile fibres, especially natural fibres, textile materials are likely to display various distinctions. The degree of variation is also increased by the nature of converting processes. This is one of the dominant reasons for occurrence of defects in textiles.

In general, defect is defined as an imperfection that impairs worth or utility. It may be absence of something necessary for completeness or perfection or a non conformity. ISO/IEC 9126 distinguishes between a "defect" and a "nonconformity", a defect being the nonfulfillment of intended usage requirements, whereas a nonconformity is the nonfulfillment of a requirement. In a product more than one defect may be present and a relatively small number of minor defect may be acceptable to the customer.

Woven fabrics are produced by interlacing of two sets of straight yarns by means of weaving technique. The weaving technique is the intersection of warp and weft yarns which cross and interlace at right angles to each other in accordance with a given pattern. The lengthwise yarns are known as warp yarns and width wise yarns are known as weft or filling yarns and the fabric produced is known as woven fabric. A number of faults are likely to occur in fabric during the course of weaving process.

A Fabric defect is any abnormality in the fabric that hinders its acceptability by the consumer. Fabric faults or defects, are responsible for considerable amount of defects found by the garment industry. An automated defect detection and identification system enhances the product quality and results in improved productivity to meet both customer demands and to reduce the costs associated with off quality. This fact makes the identification and remedy of defects in fabric manufacturing very critical issue. . Due to the increasing demand for quality fabrics in global competition , high quality requirements are today greater since customer has become more aware of poor quality problems. To avoid rejection of fabric, it is necessary to avoid defects otherwise, price of fabric is likely to be reduced by 45%-65% due to the presence of a number of defects. This fact is one of the driving factors of development of an expert system for defect diagnosis.

Several characteristics of woven fabrics are determined by the raw materials used, manufacturing technique employed, constructional parameters selected and finishing sequence adopted. However, variation in raw materials or lack of control over pre-treatment processes and application of in appropriate wet processing technology leads to the development of defects in finished fabrics. Fabric defect is a fault or lack that spoils the effective use of fabric.

There are different kind of fabric defects as many as 173 . The causes of each defect may be different or similar factors which are apparent at different departments or stages of the entire manufacturing process i.e. from spinning, winding and warping, sizing and others. The quality of the fabric at a weaving loom is determined by the entire sequences of operations from weaving preparatory to weaving. In case of a finished fabric, source of faults are also due to inappropriate setting or parameters in operations of pre-treatments, dyeing, printing and finishing

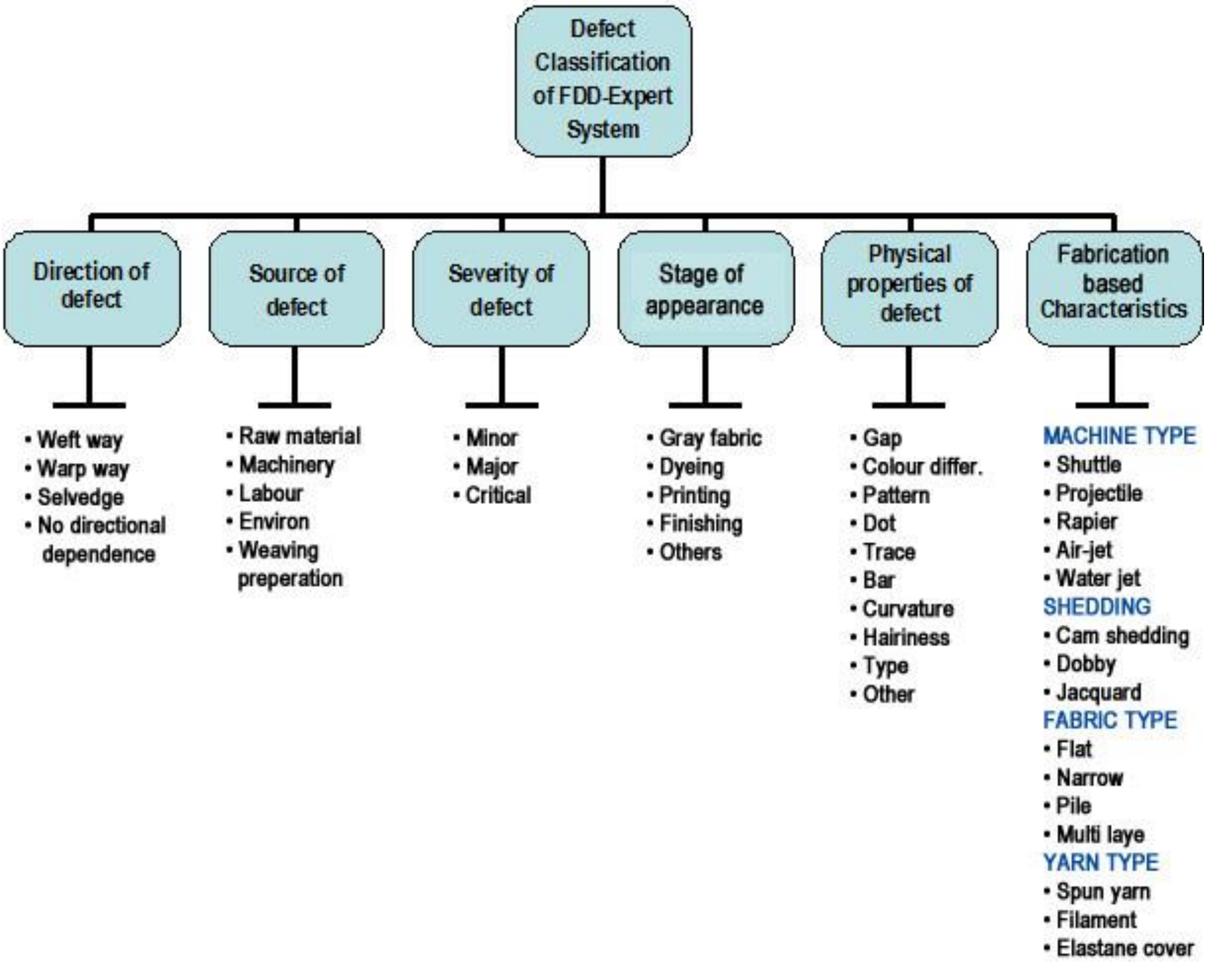

Figure 2. The list of attributes assigned to characterise woven fabric defects

Therefore, an appropriate classification system of defects considering each process in relation to the manner in it affects the subsequent process, should be developed. Woven fabric defects are identified to characterise several aspects with relevant attribute values. The characteristics for distingusihing defects are given as follows:

- The direction of defect
- The source of defect
- The severity (impact) of defect
- The stage of appearence

- Physical properties of defect
- Fabrication based characteristics
- Dimensions of defect

Defects are classifies in accordanve with attributes assigned to each characteristic class. The list of defect classification for the FDD-Expert is given in Fig.2.

Development of the FDD-Expert System

The development phases of the expert system is given in Fig. 3. The expert system is called as FDD-Expert to denote Fabric Defect Detection. The requirements of the system are:

- to define and explain possible woven fabric faults
- to reach defects by the standart defect names as well alternative names used in industry
- to make clear distinctions between all defects
- to enable user to diagnose the causes of any defect
- user friendly
- accessible defect picture archive
- tracing forward and backward between the source of fault and defect
- systematic list of solutions for remedial actions
- search engine for faults

FDD-Expert system is structured to accomplish all the requirements with a rich archives of default photographes. The expert system developed in this study is in a rule-based structure. The rule base of the system was extracted by employing the Formal Concept Analysis (Ganter and Wille, 1999) method. The first step of this method is determining the formal objects and the attributes associated with these formal objects. In the second step, the formal objects are clustered using their largest common attribute sets. The clusters that emerge in this way are called "formal concepts". A formal concept represents a set of objects with certain common characteristics in a specific domain.

In order to apply the Formal Concept Analysis method on the fabric faults domain, first the defects and their descriptive characteristics are represented in a structured way on a table. In this table each fabric defect is specified by its visual cues which are the formal attributes for this domain. In the next stage, the Formal Concept Analysis algorithm was applied to reveal the clusters of fabric faults, which are the formal concepts. The structure of relationship is given in Fig.4. In this study, a parallel and recursive algorithm in the FCALGS library (Krajca et al., 2008) was used for applying Formal Concept Analysis.

The most important advantage of using Formal Concept Analysis on this expert system is that fabric defects with common features can be easily grouped and presented to the user, without the obligation of providing all properties of a specific fabric defect. Formal concepts revealed by using fabric defects and their visual characteristics are automatically converted into Prolog syntax. Prolog is a general purpose logic programming language and is especially used in artificial intelligence programming. In Prolog, as a declarative programming language, program structures are coded as facts and rules in the knowledge base. Automatic deductions can be extracted through this knowledge base by a logic interpreter. Allowing automatic logical deductions from facts and rules, Prolog provides an elegant way of developing expert systems.

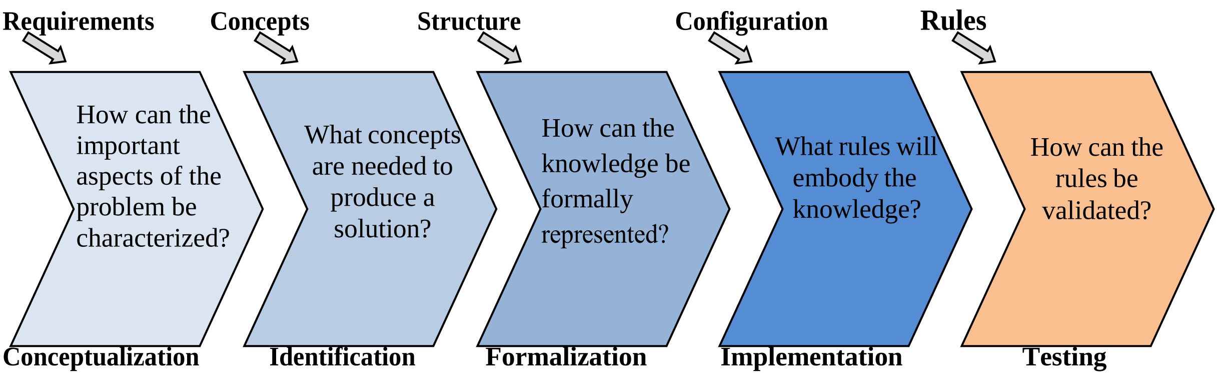

Figure 3. Development phases for expert system building

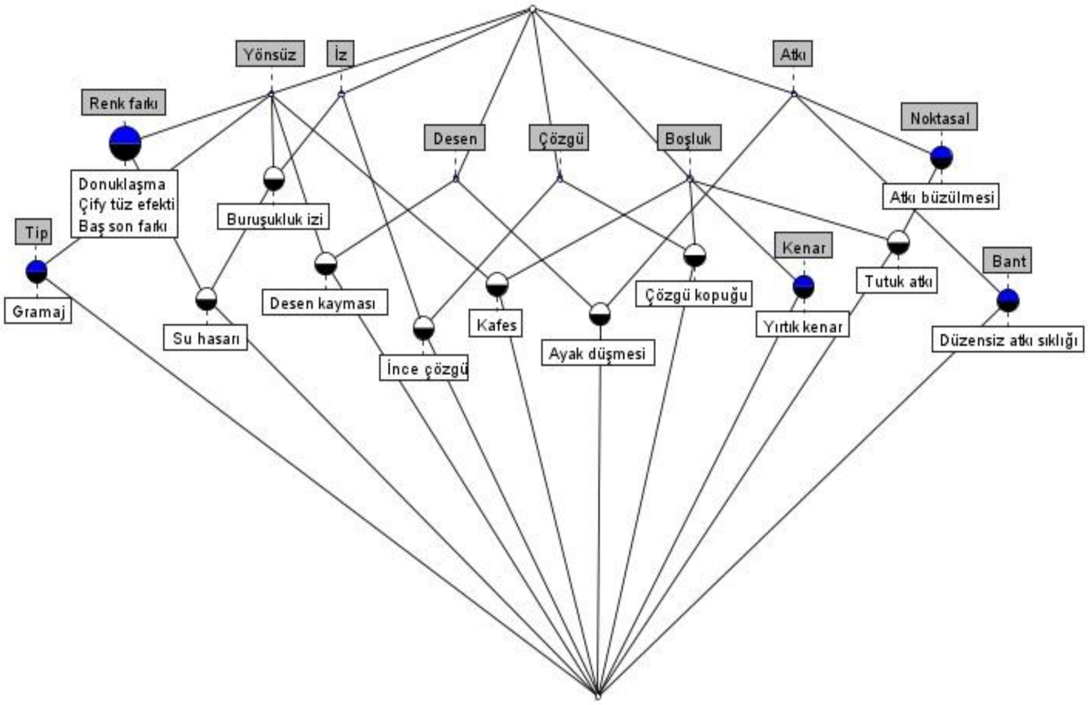

Figure 4. Conexp lattice realitionship diagram for Formal Concept Analysis of defects and their attributes

For the domain at hand, the concepts extracted by using the Formal Concept Analysis are converted to Prolog syntax by coding both the fabric fault clusters and their attributes as list structures in the form of facts. In order to implement this rule-based programming infrastructure, SWI-Prolog (Wielemaker et al., 2012), which is an open source Prolog distribution, was used in this study. The modules that constitute the background part of the expert system have been made user-friendly by developing a screen to allow the user for selecting the visual cues for fabric faults. The user is able to see both the possible causes of a defect and solutions for remedy on the same screen, by simply selecting the visually identified cues.

Analysis and Findings

According to the proposed framework, the defects of woven fabrics are classified in terms of characteristics. The interface of expert system with dialogue panels makes the search and diagnosing process easier and quicker. The opening scree of the system is given in Fig. 5. User is expected to select or mark apparent characteristics of any defect on the basis of attribute values. There are six groups of characteristics to enable the user to outline any defect. These defect attributes or cues are basic and simple criteria to prevent any subjectivity.

The development of the defect database are carried out in collaboration with 5 large scale weaving mill. Their expertise knowledge on defining faults and finding appropriate solution are separately collected and integrated into the database.

The FDD expert system is capable of tracing the defect even with one characteristic. But the more attributes selected, the quicker the diagnosing of defects. The first characteristic to be marked is likely to be the direction of the defect. This selection brings the list of all relevant defects. Then selection of a characteristic for physical appearance of the defect shortens the list with defects having two common characteristics. The selection of fabrication based characteristics such as the machine type, yarn type or fabric type apeear to enhance the diagnosing ability of the system. User may select any defect from the list of possible defects, to see specific causes for that particular defect as seen in Fig.6. In order to see the possible ways of eliminating or remedying the source of defect, that specific cause has to be marked. It is also possible to use a search engine to reach any defect in the database.

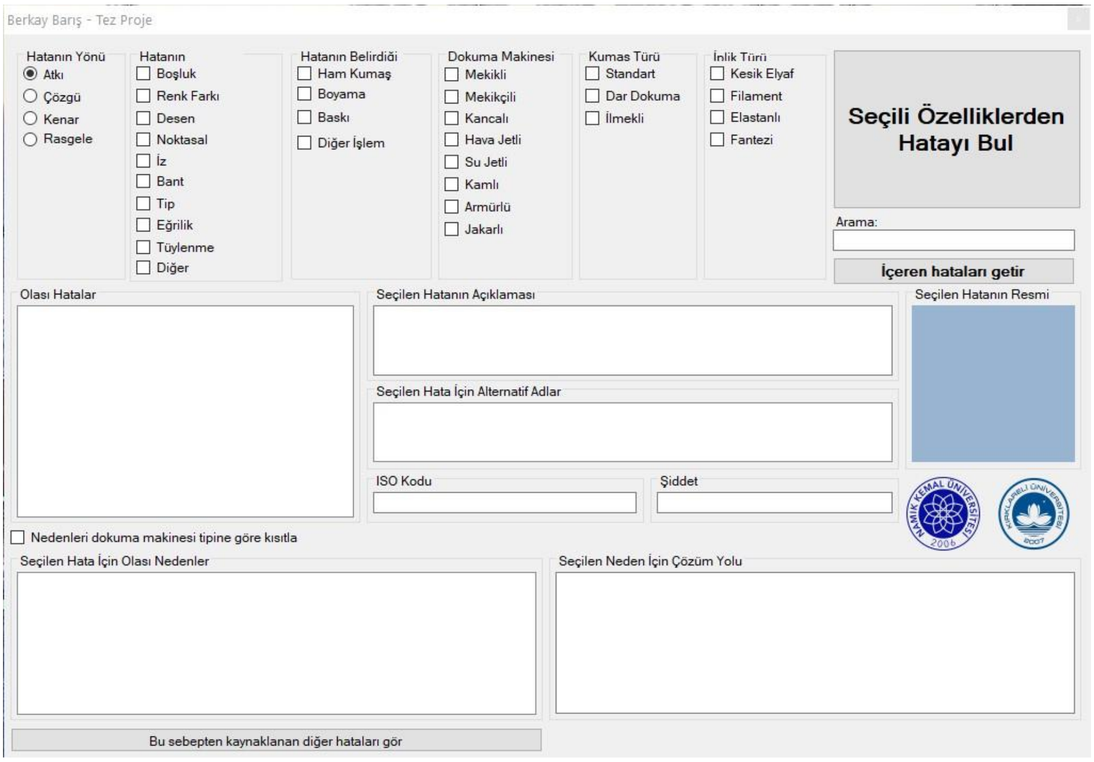

Figure 5. Opening screen picture of the FDD expert system

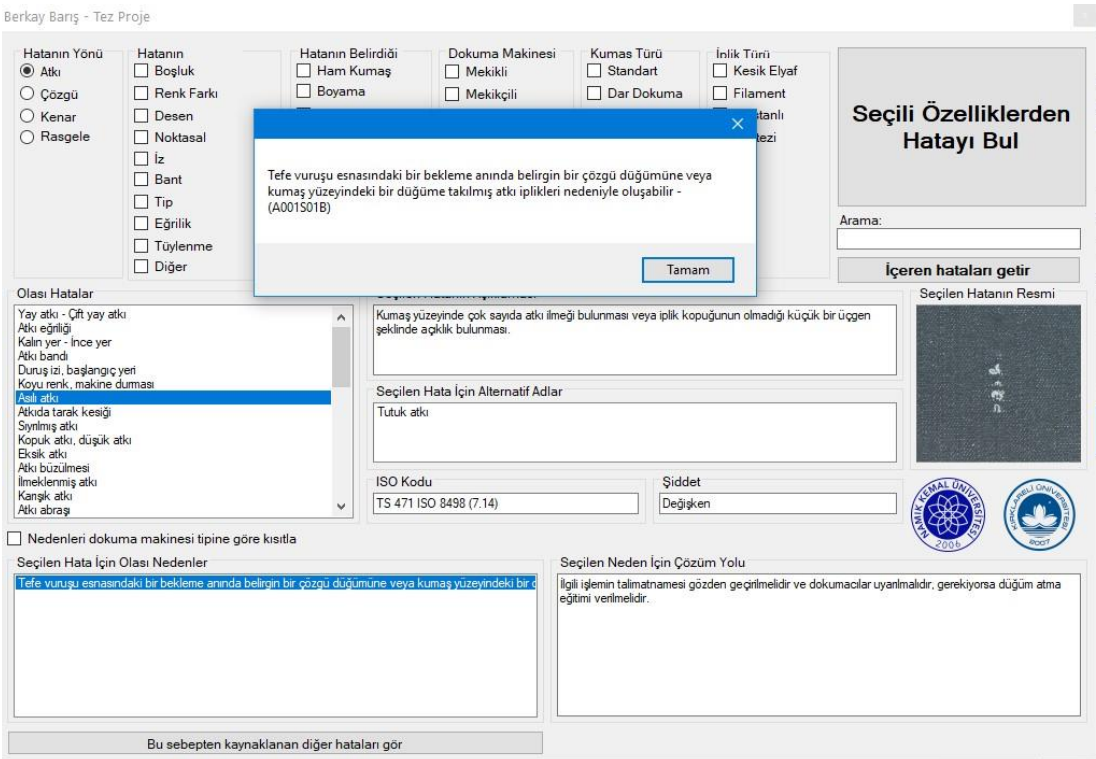

Figure 6. The list of defects relevant to weft way direction and causes and solution for a specific defect

The quality inspection operators and department managers of the five weaving mill are asked to test the FDD expert. They have used the system for diagnosing certain defects and defects specific to their mill. The majority of 177 defects have been tested. The performance of the expert system on the basis of user friendliness, correctness of the knowledge, accessibility to the root causes and remedial solution was found satisfactory.

Conclusion

This study was focused on development of an expert system for diagnosing defects based on a systematic defect classification. The systematic classification of defects on the base of various characteristics has been one of the important outputs of the work. On may say that it is the most important stage to develop a reliable database. The potential sources of faults and possible solutions to eliminate that fault and the resultant defect are also included in the database under systematic and standard headings. The expected impact of this database is to offer a standard terminology and a systematic fault tracing methodology for industrial users. The trials with the developed expert system proved that the expert system Works efficiently and a useful detect diagnosis and remedy tool in case of rarely seen defects. It is also found useful for training of fabric inspection operators as well as weaving loom fixers.

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