An Intelligent Eddy Current Signal Evaluation System to Automate the Non-Destructive Testing of Steam Generator Tubes in Nuclear Power Plant

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Abstract - This paper describes an intelligent system to automatic evaluation of eddy current(EC) signal for inspection of steam generator(SG) tubes in nuclear power plant. Some features of the intelligent system design in the proposed system are : (1) separation of representation scheme for event capturing knowledge in EC signal and for structural inspection knowledge in SG tubes inspection; (2) each representation scheme is implemented in differnt methods, one is syntactic pattern grammar and the other is rule based production. This intelligent system also includes an data base system and an user interface system to support integration of the hybrid knowledge processing methods. The intelligent system based on the proposed concept is useful in simplifying the knowledge elicitation process of the rule based production system, and in increasing the performance in real time signal inspection application.

INTRODUCTION

Eddy current testing (ECT) is a popular non-destructive evaluation (NDE) method and it is widely used in inspecting steam generator(SG) tubes and nuclear fuel tubes in the nuclear power plant. Conventional ECT has been done by human expert's inspection of the EC signal from tubes through the real time data acquisition equipment. Because of the growing number of nuclear power stations with extended in-service history, the importance of the reliable and practical ECT for SG tube inspection is increasing[4]. There have been some attempts including our institute to automatically evaluate eddy current (EC) signals of steam generator tubes to solve some problems caused by conventional ECT [5-10].

Currently, SG tube inspection in nuclear power plants is done by the certified high quality inspector. The inspector identifies flaws from the signals continuously displayed on the computer monitor. The inspector has to look into the signals of one tube thoroughly even if most of them are free from flaws. One SG has about 3000 ~ 5000 tubes and the signal size of one tube is about 1 Mbytes. The inspector typically looks into the signals for 8 - 12 hours a day and this increases the possibility of incorrect evaluation by the inspector. Furthermore, the interpretation of the signals varies depending on the skills and tastes of the human inspectors. And the mistakes of the evaluation directly and critically affect the safety of the nuclear power plant operation[4].

There are some technical difficuties in building a practical system which automatically evaluates the EC signals to solve the above problems. First, the size of input raw data is too large and variabe to be processed using an on-site real time field computing environment. Thus, it requires a proper preprocessing mechanism which can reduce the input data effectively. Second, since the EC signals generally contain heavy noise and distortion, it is too ambiguous and uncertain to represent knowledge for signal interpretation using a conventional rule based approach.

To meet these requirements, an expert system is designed and implemented to improve the reliablity and practicality under the on-site processing conditions. In the proposed intelligent system, syntactic pattern recognition subsystem and rule based production subsystem co-work. It adopts a syntactic pattern recognition subsystem to represent the characteristics of EC signal, to capture flaw - suspected events correctly, and to discard most of the non-defective normal signal. And it adopts a rule based production subsystem to represent knowledge of event signal evaluation for SG tube inspection in nuclear power plant.

OVERVIEW OF THE PROPOSED SYSTEM

The SG inspection task is a process which drives and modifies a series of events to achieve the following steps of subtasks:

i) to detect the flaw events,

ii) to categorize the flaw events,

iii) and (if necessary) to evaluate the parameters of the flaw events

In our approach, there are two kind of knowledge representation manner. One is that the knowledge that belongs to i) and ii) subtasks is represented in a syntactic grammar based adative pattern recognition system. The other is that knowledge that belongs to ii) and iii) subtasks is represented in IF..THEN style rule base system. The former is highly related to the noisy raw EC signal and the latter is related to quantitative parameters measured from the flaw event. To integrate the two kinds of knowledge representation, the proposed system has a 2 layered hybrid architecture. The Fig.1 shows the overview of the proposed system architecture.

In Fig. 1, the event extraction subsystem acquires the raw EC signal in real time through IEEE 488 protocol. Within the interval period of data acquisition between tubes, the event extraction subsystem quickly extracts all flaw-suspected event signals and skips the most portion of non-defective normal signals.

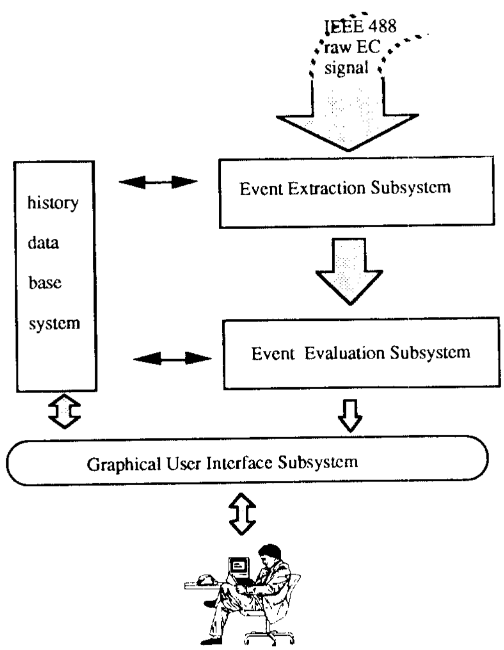


Fig. 1 The overall architecture of the expert system

Some previous studies [5-10] show common problems of complexity in event signal extraction stage. To reduce the complexity in raw data processing, a syntactic pattern recognition system is introduced in the event extraction subsystem. Therefore, the shape and trajectory of the EC signal - the most important two factors in evaluating the EC signal , are exactly represented by the syntactic string. And the knowledge for extracting flaw suspective event signal is represented in grammartical rules in a syntactic pattern recognition system.

The event evaluation subsystem decides whether each of the flaw suspected events has defects or not, analyizes flaw characteristics and generates decision reports. All knowledge in the subsystem are represented in the form of data object and rule object format.

The graphical user interface subsystem shows the evaluation results produced by expert system through various point of view to help final validation by user.

And a data base management system inteacts with all subsystems in the global system to handle various data. The subsystem is designed in such a way that the events which the system can not evaluate with high level of confidence are left to inspectors' decision.

EVENT EXTRACTION SUBSYSTEM

1. Representation of EC signal

In the event extraction subsystem as shown in Fig. 1, a certain amount of continuous EC signal is transformed to a string which is composed of the special characters, called pattern primitive character. The basic concept to evaluate the EC signal is that the horizontal and vertical components are combined and displayed in the lissajous plane (X-Y plane), and that the shape traced is interpreted as shown in Fig 2.

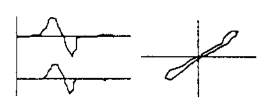


Fig. 2 Two EC signal components and lissajous display

As shown in Fig.2, the evaluation of EC signal means the interpretation of the shape and trajectory for the signal displayed in the 2-dimensional lissajous plane. Therefore, the pattern primitive characters must fully represent the above two factors - shape and trajectory. We can adopt the 8-direction code which is widely used to recognize shapes in 2-dimensional plane [1]. However, the pure 8-direction code can not represent the trajectory of the signal when the horizontal and vertical values shift without amplitude transition. In that case, the situation is traced by a static dot in the lissajous. To do this, we define one more direction represented by 'a' code. Fig. 3 represents the 9-direction code for the pattern primitives characters. The range of each primitive has about 45 degree except the 'a' primitive in Fig. 3.

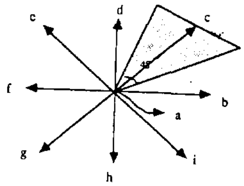


Fig. 3 9 direction pattern primitive characters

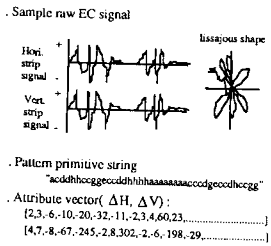


Fig. 4 Transformed Representation Example

Fig.4. shows an example of tranformation from a certain amount of raw EC signal to string and attribute vector based representation.

2. Recognition of Event Signal

The event extraction subsystem in Fig. 1 has two tasks, one is the extraction of event signal in the continuous input signal, the other is the measurement of all parameters for the event. For the purpose, knowledge to understanding EC signal is represented in grammatic rules and a new data-driven inferencing mechanism based on a syntactic parsing method is design and implemented in the event extraction subsystem[10].

Fig. 5 shows an event signal samples and all the parameters produced by the data-driven inferencing mechanism. The parametes in Fig.5 are utilized by next level subsystem to evaluate the seriousness of the event. The capability is one of the advantages addressed in the syntactic pattern recognition approach.

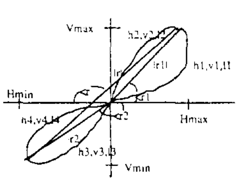


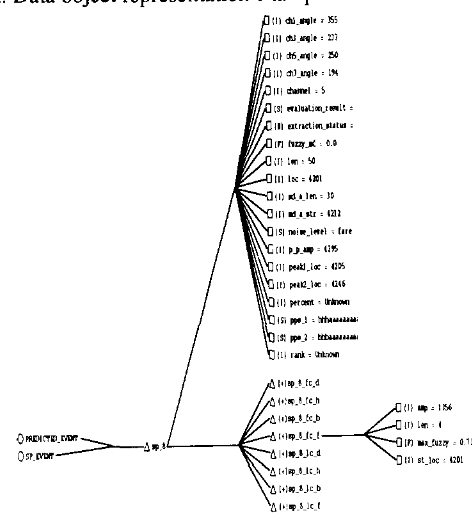
Fig. 5 an extracted event and related parameters

EVENT EVALUATION SUBSYSTEM

The inspectors categorize defects using such knowledge as structural details of SG, inspection procedure, data acquisition method applied, history of the defect location, as well as information such as shape, trajectory, size and location of the defect.

Hence the knowledge used for the flaw categorization can be globally classified into two kinds : knowledge obtained directly from the raw EC signal and knowledge obtained from other source. The former can be used in the lower level subsystem. The data objects whose values were filled in lower level subsystem are shown in Fig. 9a. Fig. 9a shows that the sp 8 object categorizes into both PREDICTED EVENT and SP EVENT classes and it has number of property slots and subobjects. Some values of property slots and subobjects are filled in the first level and second level subsystems, the latter being represented in terms of group of rule objects as shown in Fig. 9b in the 3rd level subsystem. Therefore, the rules in Fig. 9b are simultaneously fired when it encountered data objects required such as sp 8 in Fig. 6a.

a. Data object representation examples



b. Rule object to control lower level subsystem example

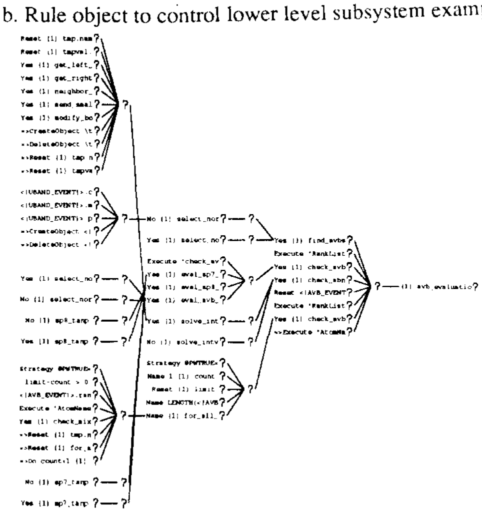


Figure 6. Knowledge Representation Samples

The entire acquired knowledge is conceptually modeled in Fig 7. Each node in Fig. 7 denotes a rule group and each links denotes knowledge hierarchy.

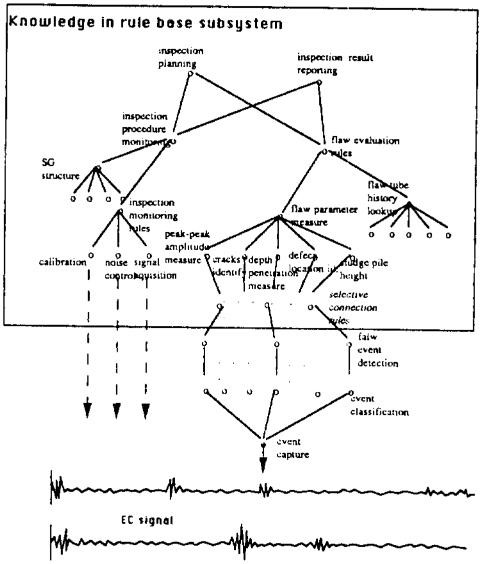


Fig. 7 Modeling of the Domain Knowledge

The top level knowledge groups in Fig. 7 report the types of the flaw and seriousness of it. The elements of the specialized final defects are as follows:

. Inner degradation defect or outer degradation defect

. Refined classification of the indicated event;

. artificial machining	. shock
. restart roll	. foreign object
. pilgrim noise	. general corrosion
. S.C.C.	. fretting or vibration
. U-bend limit	. I.G.A.
. denting	. dimensional vibration
. sludges	. other or unknown

And the seriousness of the defects are reported in term of the percent of the degradation, size of sludge pile, length of the crack, and depth of the loss, etc. All the behaviors of the human inspector to report and explain the reason and effects of the defect tubes are also modeled in in Fig. 7. The rules groups as shown in Fig. 7 are represented in rule object style as in Fig. 6b.

USER INTERFACE SUBSYSTEM

The entire view of user interface subsystem is shown in Fig. 8. The Fig. 8 is divided by 4 individual graphic subwindows :

(a) window is the top menu of the proposed expert system,(b) window represents array of tubes for a steam generator in nuclear power plant, (c) window shows the shape of one tube, and (d) window displays real raw signal.

While the expert system running, (b) window can show the inspection situation, flaw tube configuration, etc., (c) window can show just where the flaw existed in the tube and (d) window can show the seriousness and reason of the flaw by displaying real EC signal. Each windows in Fig.8 are indepentantly and simoltenously operated by the inter communication process(IPC) mannar in UNIX system.

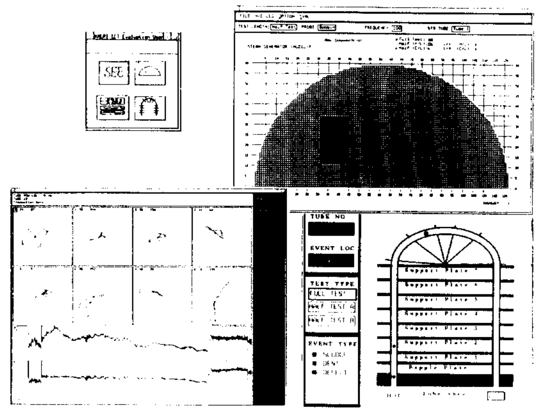


Fig.8 Windows of user interface subsystem

HISTORY DATA BASE SYSTEM

As shown in Fig.1 , the history data base system in the proposed system has two different operating modes; one is the operating mode to supply information or knowledge for execution of event extraction and evaluation subsystems. And, the other is the operating mode, via way of user interface subsystem, to supply information for final validation by human expert , to archive evaluation result and to generate several inspection reports.

The history data base system uses ORACLE as a data base management kernel.

CONCLUSION

The major design principle of the system is separation of the two tasks, event extraction and flaw event decision from the rule based expert system. This separation of the tasks increases the reliablity and enhances the practicability of the field inspection of steam generator tubes nuclear power plants. Because of the insufficient knowledge elicitation for event evaluation subsystem, the quality of the final inspection result is not measured yet. However, the defect detection performance averages 98 % for all calsses of events which is superior than LEVEL III - the most quilified human inspector. Particularly, the ratio of non - flaw event signal extraction is drastically reduced and the ratio of number of indicated tubes per a ECT is less than 30%. It means that the proposed system can reduce about 70% of human tasks. The performances of the expert system mean that it increase the reliablity of ECT and drastically reduce the time to inspect steam generator tube in inner service inspection(ISI) of nuclear power plant.

The development environment using C language makes the implementation easier with the embedded subsystems such as Nexpert callable library, X tool kit, ORACLE under the HP 9000/370 HP-UX computer system.

ACKNOWLEDGEMENTS

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