OUTLINE OF AN EXPERT SYSTEM FOR DAMAGE ASSESSMENT OF EXISTING STRUCTURES

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ABSTRACT

A computer-based damage assessment system called SPERIL has been developed under the joint research of Purdue University and University of Tokyo. The formalization of expert system which includes the methods of knowledge engineering is adopted in the SPERIL. To realize effective utilization of uncertain and fuzzy knowledge involved in the damage assessment problem, a rational inference mechanism based on the extension of Dempster & Shafer's theory is employed in the SPERIL to integrate several observed evidences.

1. INTRODUCTION

To evaluate the safety and reliability of existing structures against future hazardous events, the current safety or damage state of each structure should be assessed as accurately as possible. Yao reviewed the role and the state-of-the-art of damage assessment techniques [1,2]. For example, those few structures which suffer total or partial collapse are easy to identify. For most structures which remain standing, however, it is difficult to assess their true damage states and to determine whether and/or how each structure should be repaired.

The state-of-the-art of damage assessment is that relatively few structural engineers are capable of making such decisions on the basis of their professional experience. Moreover, the transfer of this complex decision-making practice to younger engineers depends primarily on close working relationship with these experienced engineers. To date, several methods of structural damage assessment have been proposed [1], and some related works on the failure resistance evaluation of existing structures have been reported [3-6]. However, a rational and systematic approach to the damage assessment problem has not yet been established.

In 1979, Fu and Yao suggested that the problem of the damage assessment can be considered in terms of the theory of pattern recognition [7]. Since 1980, Ishizuka et al. have chosen an expert system approach as a development tool for a computer-based damage assessment system. New rule-based inference procedures have been developed for this purpose [8-12]. This report outlines a rule-based damage assessment system called SPERIL version-1 along with its theoretical basis [13,14]. Although the currently implemented rules of SPERIL are expected to be updated with more accurate and more specific rules, it can be said that this first version demonstrates a systematic approach for the computer-based damage assessment system.

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2. THEORETICAL BASIS

The expert system basically consists of 1)knowledge base and 2)inference machine. Figure 1 shows a simplified diagram of the expert system. Expert systems for medical consultations are described in [15-19].

Ishizuka et al. proposed a AND/OR/COMB graph for representing hierarchical structures of problem with uncertainty [9,11]. Figure 2 shows an example of the AND/OR/COMB graph. The combination relation denoted by COMB refers to such a problem decomposition that a goal or subgoal is supported from plural uncertain knowledge and/or evidences which are independent with each other. There exists a consensus that min and max operations on a certainty measure can be adopted for the inference to integrate the evidences with AND and OR relations, respectively.

As for the COMB relation, the following inference methods have been proposed to date. An intuitive combining function was employed in MYCIN to integrate the evidences with the COMB relation [15]. Duda et al. proposed subjective Bayesian method for the same purpose [20]. Afterwards, the importance of Dempster & Shafer's theory [21,22] is recognized [9,23-25]. This theory enables us to deal with subjective uncertainty in a theoretical manner. Ishizuka et al. extended the Dempster & Shafer's theory to include fuzzy subset [9,11,12] and have successfully employed it in the inference machine of the SPERIL.

With this inference mechanism, a certainty measure can propagate through a hierarchical inference network. Eventually, based on the certainty measure at the final goal, the system can deduce a reasonable answer for a given situation.

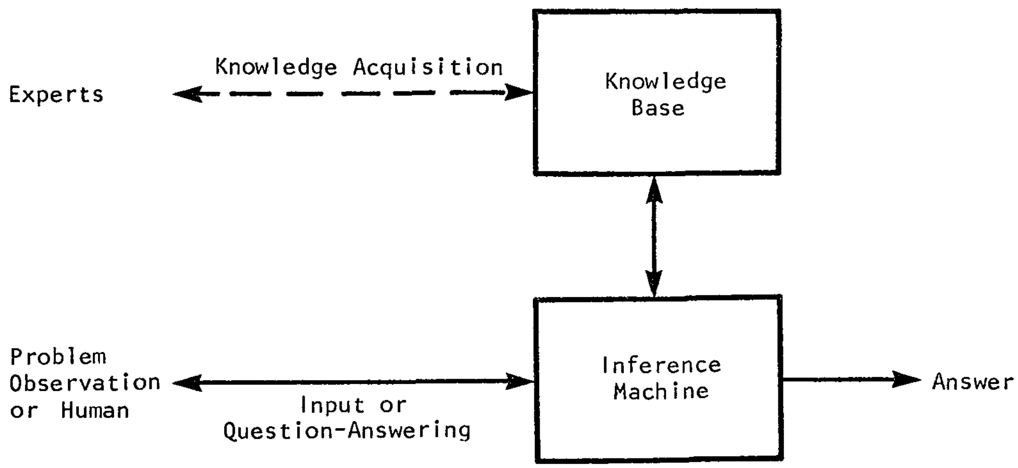

Fig. 1 Expert system.

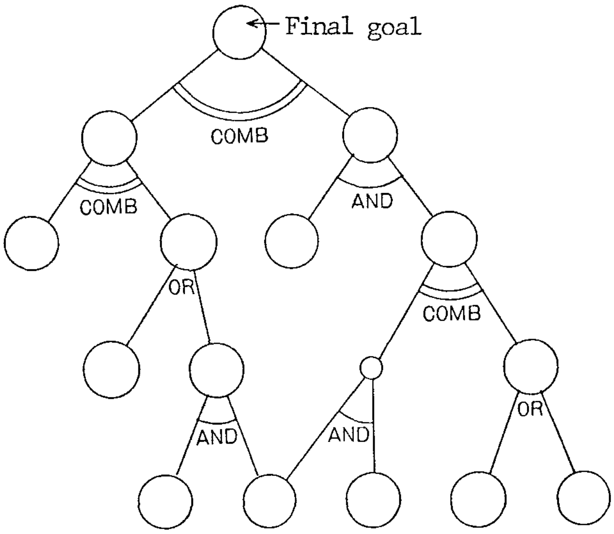

Fig. 2 An example of AND/OR/COMB graph for a problem with uncertainty.

3. OUTLINE OF SPERIL

SPERIL is a rule-based damage assessment system of existing structures particularly subjected to earthquake excitataion. In SPERIL version-1, separate evidential observations are integrated on the basis of the extended Dempster & Shafer's theory for fuzzy subsets.

Useful information for the damage assessment comes mainly from the following two sources; (1) the visual inspection at various portions of the structure and (2) the analysis of accelerometer records taken during the earthquake. The interpretation of these data is influenced to large extent by the particular kind of structure under consideration, such as the material, hight and design of the building. The useful pieces of knowledge have been collected under the organization of Fig.3 and expressed in a stylized rule format in the knowledge base.

The rule format is designed so that both human and computer can interprete it easily as exemplified in Table 1. The first two digits of each four-digit rule label are rule set number corresponding to the node number in Fig.3. To express the knowledge with fuzzy grade, the following subset are allowed;

no,
slig (slight),
mode (moderate),
seve (severe),
dest (destractive),
uk (unknown--universe set),

the membership functions of which are defined as Fig.4. In rule interpretation, the fundamental function of production system, i.e. "if premise is satisfied, then action takes place," is emphasized. The action in this case is an updating process of STM corresponding to the subgoal.

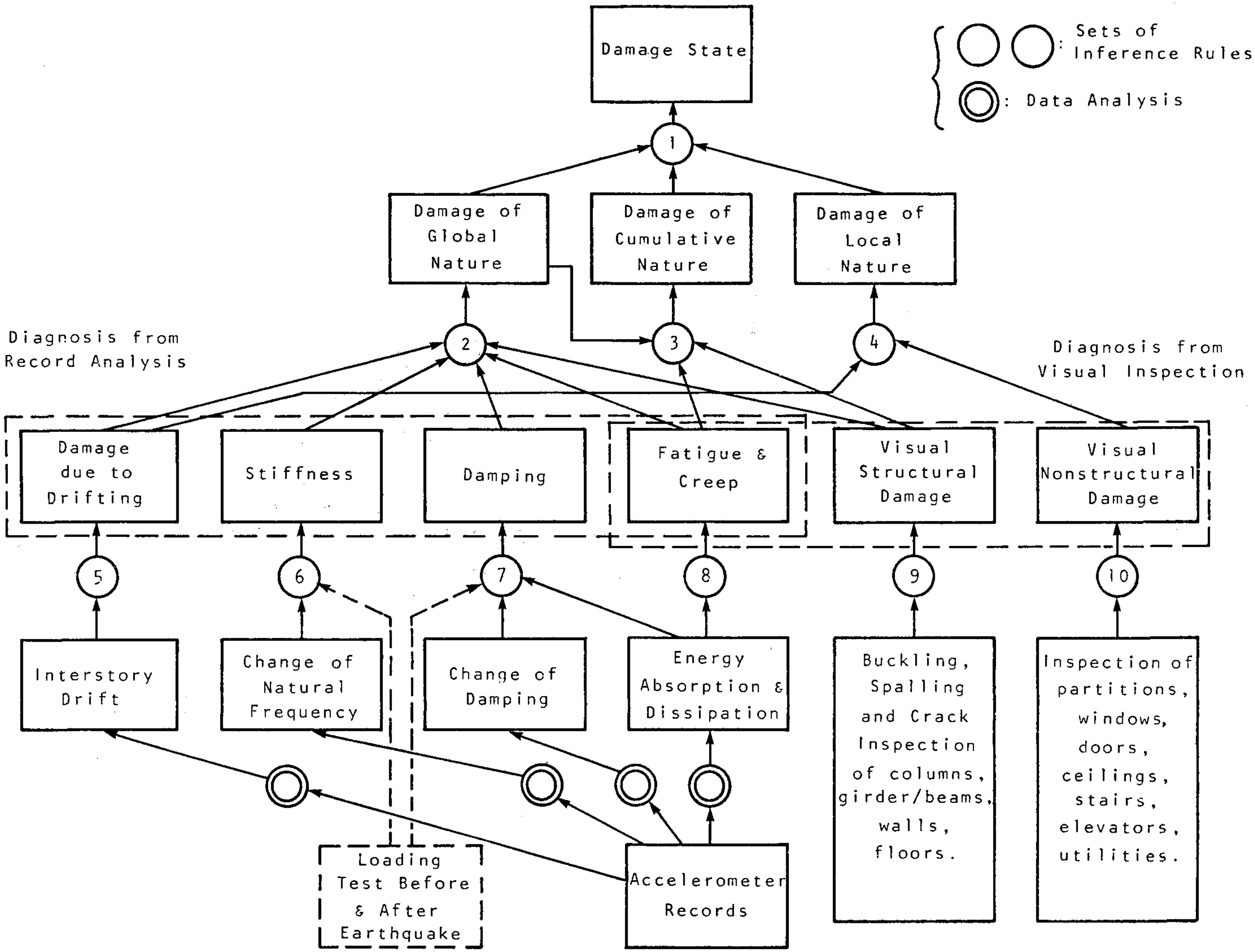

Fig. 3 Inference network of SPERIL.

Table 1 Example of rules in SPERIL.

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Rule0201
    IF:MAT is   r/c
THEN IF:STI is   dest
   THEN:GLO dest 0.6
ELSE IF:STI is   seve
   THEN:GLO seve 0.6
ELSE IF:STI is   mode
   THEN:GLO mode 0.6
ELSE IF:STI is'  slig
   THEN:GLO slig 0.6
ESLE IF:STI is   no
   THEN:GLO no   0.6
   ELSE:GLO uk


Rule0501
    IF:MAT is   r/c
THEN IF:ISD <=  -8.9
   THEN:DRI uk   1
ELSE IF:ISD <=   0.4
   THEN:DRI no   0.9
ELSE IF:ISD <=   0.8
   THEN:DRI slig 0.9
ELSE IF:ISD <=   1.3
   THEN:DRI mode 0.9
ELSE IF:ISD <=   2.0
   THEN:DRI seve 0.9
ELSE IF:ISD >    2.0
   THEN:DRI dest 0.9
   ELSE:DRI uk
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Rule0901
     IF:MAT is   steel
THEN IF:S01 is   yes   (partial collaps)
   THEN:VST dest 1
ELSE IF:S02 is   yes   (buckling of column)
   THEN:VST dest 0.5
    and:VST seve 0.5
ESLE IF:S03 is   yes   (buckling of girder/beam)
     or:S04 is   yes   (buckling of diagnal bracing)
     or:S05 is   yes   (deformation or loosing of joint)
   THEN:VST seve 0.9
ELSE IF:S06 is   yes  (spalling/crack on shear wall)
   THEN:VST mode 0.8
ELSE IF:S07 is   yes  (spalling/crack on exteria/interia wall)
     or:S03 is   yes  (spalling/crack on floor)
   THEN:VST mode 0.5
    and:VST slig 0.5
ELSE IF:S01 is   no
    and:S02 is   no
    and:S03 is   no
    and:S04 is   no
    and:S05 is   no
    and:S06 is   no
    and:S07 is   no
    and:S08 is   no
   THEN:VST no   1
   ELSE:VST uk
```

Abbreviatins

dest	destructive
seve	severe
mode	moderate
slig	slight
no	no
uk	unknown
r/c	reinforced concrete
GLO	damage of global nature
DRI	damage due to drifting
STI	damage of stiffness
VST	visual damage of structural member
MAT	material of structure
ISD	interstory drift
S01 ⁝ S08	check items of visual structural damage for steel

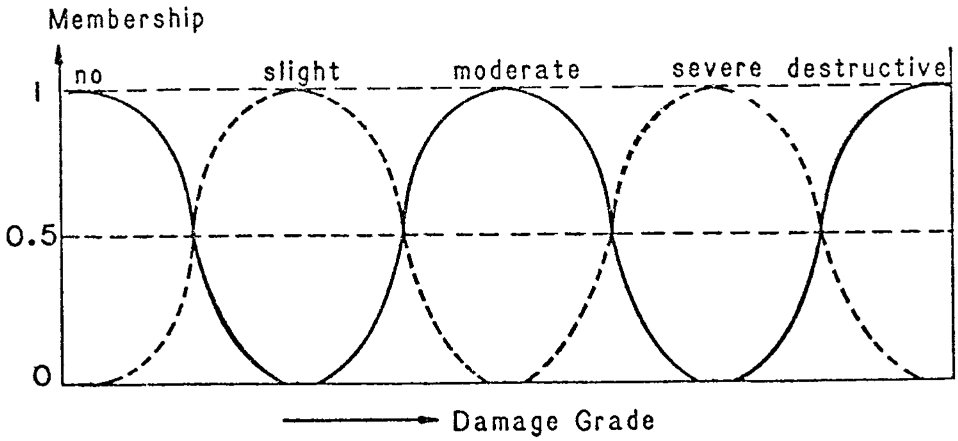

Fig. 4 Membership functions of fuzzy subsets in SPERIL.

STMs are working memories in which input data or inferred data are stored. In SPERIL version-1, the following four types of STM are used;

type-1 certainty measures of fuzzy damage grades,
type-2 linguistic data,
type-3 numerical data,
type-4 yes-no data.

When the STM is accessed, the type of STM is referred to proceed to an appropriate interpretation of the rule statement.

Because the inference network is not deep, no sophisticated strategy of rule invocation is adopted. The sequence of rule set invocation is pre-assigned as follows;

"05" "06" "07" "08" "09" "10"
"02" "03" "04" "01".

This corresponds to a bottom-up search.

Control & inference process finds and examines a relating rule in the rule-base. If STM is found in the examination of the premise to be unanswered, a question is initiated to get data. The question is generated referring to a question file, in which an appropriate question sentence is stored for each STM which has the possibility of accepting data from operator. To avoid the situation of annoying and unnecessary questions, "skip pass" is provided in the control flow for the case that there is no possibility for later action to be taken. Thus, only a minimum number of necessary questions is initiated for the purpose of inference.

After one rule is processed, the result is used to update the STM. For type-1 STM, the updating is excuteted by the extended Dempster & Shafer's theory. A final decision is made according to Dempster & Shafer's lower probabilities of fuzzy subsets in final goal. If no fuzzy subset has the lower probability larger than a certain threshold (0.2), SPERIL selects no appropriate answer. Therefore, the answer is one of the followings;

1) no damage,
2) slight damage,
3) moderate damage,
4) severe damage,
5) destructive damage,
6) no appropriate answer.

Knowledge about repairing actions has not yet been implemented. The control & inference part of the SPERIL is written using C-language. The SPERIL is currently running on UNIX operating system at Purdue Univ. and Univ. of Tokyo.

4. CONCLUSION

A computer-based damage assessment system of existing structures, called SPERIL version-1, has been developed. Expert system approach and, in particular, inference procedure with uncertainty and fuzziness based on the extended Dempster & Shafer's theory has been employed in the SPERIL to integrate separate evidential observations. Another application of this theory in a related problem is described in [26]. The advantage of the expert system approach is that it has large capability of dealing with wide variety of structural conditions involved in the damage assessment problem.

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