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A RULE-INFERENCE METHOD FOR DAMAGE ASSESSMENT OF EXISTING STRUCTURES

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16. Abstract (Limit: 200 words)

A damage assessment methodology to determine the damage states of existing structures after an earthquake is described. A definitive and rational methodology can contribute to correct decisions in repairing structures, predicting future damage, and improving technologies for aseismic structures. The proposed approach implements an inference or reasoning procedure similar to that used by experts in computer programming. It consists of a question-and-answer subsystem which facilitates an efficient interactive man-machine interface and responds upon request of the user and controller to collect necessary data for assessment. Data include field observations and as much structural information as possible with respect to the building being assessed. Time-records of the accelerometers located in various stories are analyzed in the pattern recognition system. A block of control, inference and classification sends requests to the connected blocks to accept necessary information. The inference is performed consulting a knowledge base, and the result is classified into one of the damage state categories and reported through output processing. Recent full-scale dynamic tests will be useful in developing a new methodology for damage assessment of existing structures.

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	Design criteria	Dynamic tests

b. Identifiers/Open-Ended Terms

Earthquake Hazards Mitigation

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1. INTRODUCTION

The state-of-the-art in damage assessment of existing structures is such that relatively few experienced engineers are qualified to practice it well (e.g., [1-3]). The damage assessment to be considered here deals with the determination of the damage state after an earthquake. It is desirable to obtain a definitive and rational methodology which can contribute not only to the correct decision for the repair of structures but also to the prediction of future damage, and the improvement of technologies for aseismic structures.

So far, several methods to assess the structural damage have been proposed. These were reviewed recently by Yao [3], who found that a complete and rational solution is not yet available. Although collapse or partial collapse is relatively easy to determine by observation, it is very difficult to assess the damage state in a precise manner when the cumulative damage is less obvious.

When accelerometers are equipped in the building, we can utilize these response data in addition to the visual observation. In this case, system identification techniques may play an important role to construct a mathematical model of the structure [4-7]. However, the actual structure is too complex to be represented precisely with a mathematical model. Moreover, most mathematical models are effective only in the linear or slightly non-linear range of the structural behavior. It is not realistic to rely wholly on the system identification technqiues, which require a well-defined form of the mathematical model in most cases.

Recently, Eu and Yao suggested that the problem of the damage assessment can be considered in terms of the theory of pattern recognition [8]. In typical pattern recognition, such as ECG and EEG analysis, shape classification or field segmentation in remote sensing, etc., there are standard patterns to which measured patterns are classified. On the other hand, in the damage assessment, each building has a different shape, size and structure, and each building is subject to a different type of the ground motion. Therefore, when we apply the pattern recognition technique to this problem, the classifier should be adaptable to each individual event.

In addition, since we do not have a well-established method to define the damage state at present, a result obtained from an analytical method has uncertainty or vagueness to some extent. The structural expert considers all the circumstances, selects a number of important factors, synthesizes some analytical results, and finally obtains the most reliable answer by using his knowledge from extensive experinece and intuition. Hence, to construct a useful damage assessment system, one approach we propose is to implement an inference or reasoning procedure like the experts do into a computer program.

2. OUTLINE OF THE SYSTEM

Figure 1 shows the block diagram of a damage assessment system which is now under design. A question-and-answer subsystem is provided to facilitate an efficient interactive man-machine interface, which responds upon request

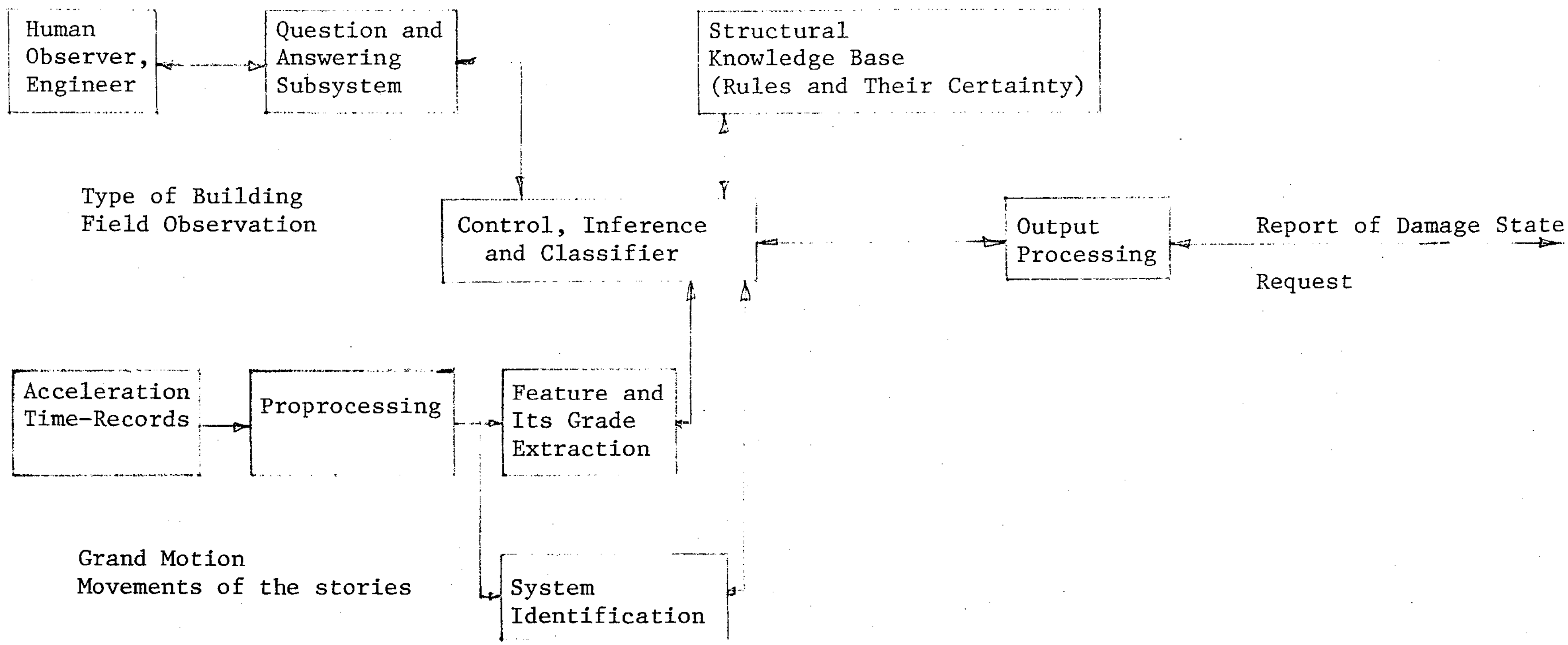

Figure 1. A Damage Assessment System for Existing Buildings Subjected to Earthquakes.

by the system user and controller to collect necessary data for the assessment. These data include the field observation and as much structural information with respect to the building in question as possible.

Time-records of the accelerometers located in various stories are analyzed in the pattern recognition fashion to extract some of helpful features for the following classification. These features may include the change of stiffness and damping during the movement and the hysteretic behavior of the displacement when it went into nonlinear and/or inelastic region [9-12]. Data analysis with the use of system identification techniques is also expected to provide useful information for the inference or the determination of the damage state.

A block of control, inference and classifier sends requests to the connected blocks to accept the necessary information. The inference is performed with consulting a knowledge base, in which the structural knowledge like those possessed by various experts is contained, to modify adaptively the collected features or the classifier to match the various conditions. This inference process will be discussed somewhat in detail in the following section. The result recognized into one of the damage state categories is reported through output processing with necessary explanations.

3. INEXACT INFERENCE

Because (a) all the existing or proposed methods relating to the damage assessment have uncertainty parts with respect to the reliability of their results and the range of their applicable objects, and (b) it is difficult even for the experienced engineers to express their decision-making process explicitly, a comprehensive methodology which synthesizes these individual techniques should have the inference or reasoning procedure which can deal with the uncertainty or ambiguity to produce the most reliable answer.

This kind of problems regarding the uncertainty are traditionally treated in terms of probability. Entropy function, minimax principle, Bayes' decision theory, etc. are the well-known techniques in this field. These statistical methods are appropriate particularly for the uncertainty problem in which random variables or noise corrupted phenomena play dominant roles.

In 1965, Zadeh presented a new concept of fussy sets theory [13,14]. This theory includes (a) expression of ambiguous linguistic variables, by means of membership functions (b) characterization of simple relations between variables by fuzzy conditional statements, and (c) inference in composite relations by fuzzy algorithm. Since then, it has been applied not only to engineering fields but also to wide range fields, such as economics, management science, artificial intelligence, psychology, linguistics, information retrieval, medicine, etc. [15,16]. In civil and structural engineering, several papers have been appeared which intend to apply the fuzzy algorithm [17-20]. It can be said that the fuzzy sets theory is a particularly useful tool dealing with the problems which are (a) represented in linguisitc expressions and (b) related strongly to human subjectivity.

Here, if we try to simulate the way of human thinking, we should recognize that there are two classes of ambiguities [21]. First one is the ambiguity or uncertainty accompanying to the definition of facts and relations between the facts. Second one is the complexity or variety of reasoning procedure. For instance, if a number of knowledge or rule modules are stored with having more-or-less possibility to contribute the decision like in the human brain, we may select a couple of major knowledge according to the circumstance in question and contruct their relation for the inference to obtain a desirable decision.

It can be said that the fuzzy set theory is useful for the first class of ambiguity. As for the second class of ambiguity of inference, we may advantageously utilize recent artificial intelligence or knowledge engineering technique [22,23].

A production system employed in MYCIN, which is an outstanding practical result of artificial intelligence, includes both classes of ambiguities as described above. MYCIN is a medical consultation computer program to assist physicians in an interactive fashion in the identification of the microbacteria of patients and its appropriate therapy selection [24]. The medical knowledge stored in its knowledge base is expressed as the corpus of about 200 individual rules. Each rule is written in the form which consists of premise (IF clause), action (THEN clause) and certainty factor of the rule itself. The certainty factor, which is a numerical value between 1.0 and -1.0, expresses how the rule is reliable or believable. For the sake of the searching efficiency, each rule is assigned to one of the node of a context tree according to the content of its knowledge.

Inference in MYCIN is performed in goal-oritented manner following the context tree. The certainty of an action is calculated by producting the degree of the certainty of the premise clause in each case and the certainty factor of the rule itself. If there are several rules in a node of the context tree supporting the same action, these certainty factors are combined by a comparatively simple formula based on the approximation of Bayes' conditional probability theory to produce a somewhat large certainty factor of the action. By a heuristic search method which pruns the inference line by a certain threshold, the most beliabable answer is found. The answer is the most appropriate therapy in this case*.

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*An explanation system using translation between natural language and machine expression, and a rule acquisition system from the experts are the other worthnoting features in MYCIN.

Comparing the inference by the fuzzy logic and the inexact inference employed in MYCIN, it can be said that the former is theoretically elegant and self-consistent and the latter is rather plausible and practical to real world problembs than theoretical. In addition, the latter has more capability to deal with the complicated situation than the former by accepting a number of knowledge as independent fragments or modules.

In the damage assessment of our problem, since it seems to be efficient to express the structure experts' knowledge as individual modules rather than a whole, the MYCIN's inference method may provide a helpful technique to design the system.

4. CONDLUDING REMARKS

Designing plan of a damage assessment system has been described. The importance of implementation of structural experts' knowledge and the role of inexact inference as well as the application of pattern recognition techniques has been emphasized and discussed. Recent full-scale dynamic test of buildings will be useful in the development of a new methodology for the damage assessment of existing structures.

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