A Knowledge-based System for Dam Safety Assessment in Taiwan

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Summary

In Taiwan, the assessment of dam safety is normally carried out by either visual inspection or statistical analysis of monitoring data. The process is time-consuming and to a great extent relies on the knowledge and expertise of the personnel. With increasing power in computing facilities, systematic approaches that adopt knowledge-based expert system techniques are potential solutions for managing dam safety in Taiwan. In this study, we investigate recent advances in this field and propose a knowledge-based expert system for conducting dam safety assessment in Taiwan. The framework and the weighting system of this system are discussed.

Keywords: dam safety assessment, knowledge-based system, web applications

1. Introduction

There are more than 80 reservoirs in Taiwan, which are important sources for water and hydraulic power supplies, flood control and tourist attractions. Failure of these reservoirs will result in enormous loss of lives and properties in the region. Therefore, the safety examination of these reservoirs, in particular the dams, is of paramount importance to the hydraulic engineering in Taiwan. Until recently, dam safety inspection in Taiwan is still carried out by visual examination or statistical analysis of the monitoring records collecting from automatic instrumentation or data acquisition systems. The interpretation of these data is generally a tedious work that requires exhaustive search and to a great extent relies on the knowledge and expertise of the personnel. However, with only limited staff, the reservoir authorities in Taiwan normally depute this work to consultant groups or companies. The examination is generally done manually and needs one or two years before compiling final reports as shown in Figure 1. This process becomes very inefficient when a strong earthquake shook central Taiwan in 1999 and caused several dams damaged in the region. Hence, the current process is unlikely to resolve the imminent problems promptly.

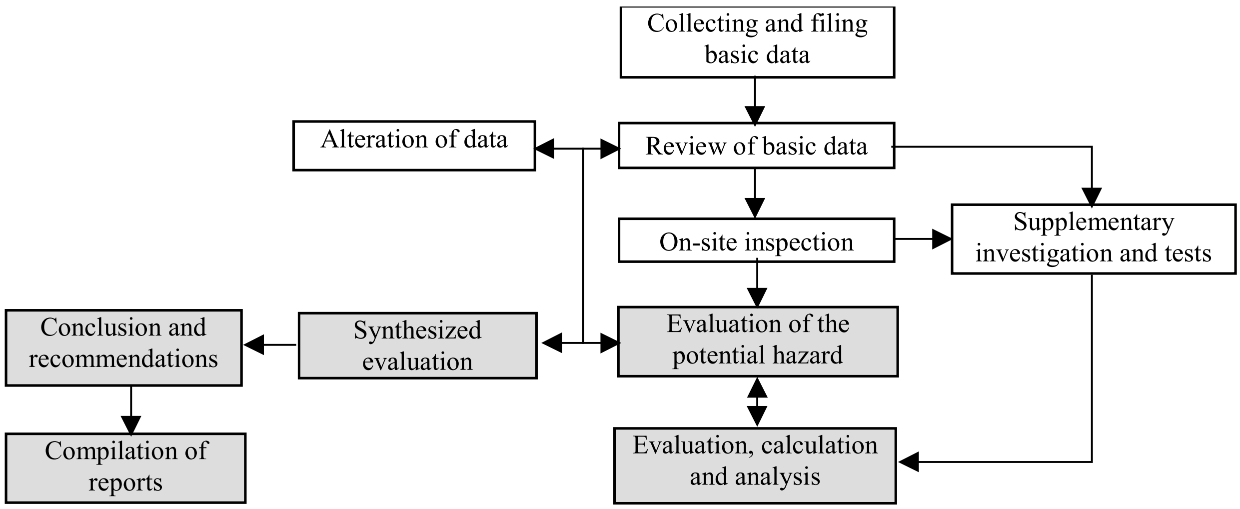

Fig. 1 Flow chart for conventional dam safety inspection in Taiwan

Knowledge-based expert systems (KBES) or expert systems are the computer programs that combine many artificial intelligence concepts and technologies to simulate the thinking of domain experts including the heuristic form of knowledge and the characteristics of non-conventional inference rules. It is clear that KBES technology opens a new direction for the assessment of dam safety. By transferring the knowledge of the visual examination of dam inspectors into the knowledge bases and inference mechanism in the system, we are able to conduct those procedures of interpretation, evaluation and analysis as shown on the grey boxes in Fig. 1 automatically. Another benefit of KBES is that the knowledge acquisition process generates unified and systematic rules and facts for the problem domain that makes knowledge transparent and the preservation of knowledge possible. Motivated by the above reasons, an knowledge-based expert system is currently under development at Sinotech Engineering Consultants, Inc. (SEC) in Taiwan. This system aims to reduce the time-consuming interpretation procedures in current inspection process in managing dam safety in Taiwan.

Further, the rapid growth of Internet has a great impact on applied information systems. The Internet has the advantages of uniform user interface, relaxation of geographical restriction, data sharing and real-time transmission. Therefore, it becomes an emerging framework for applied information systems. As dam safety inspection is a collaborative work between many organizations, for example dam authorities, government offices, engineering consulting companies/groups and research centers at the universities, it is clear that the integration of web-based technology with KBES will provide better environment for knowledge and information sharing and decision support among the groups.

With her rich experience and sources in the planning, design and safety examination of reservoirs, Sinotech Engineering Consultants, Inc.(SEC) has built up the information system using the latest web technology called “Reservoir Information System” (RIS) [2]. In this paper, we report recent advance on dam safety related information systems and KBES shells and present a web-based knowledge-based system for dam safety examination in Taiwan.

2. Review on dam safety related information systems

During the past few decades, a few countries have applied artificial intelligence techniques for managing the dam safety in their regions. Texas Instruments were among the first to take advantage of KBES technology to solve the dam safety problem. They developed the Kelly System [3] to perform data analysis and seepage detection at the Vermilion Dam. ISMES in Italy has applied artificial intelligence techniques to perform the safety examination of hydraulic structures and developed four decision support systems, *i.e.* Mistral, Damsafe, Kaleidos and Igor [4]. Among the fours systems, Damsafe targets the safety of dam and consists of three layers: an information layer, a layer of interpretation agents and a casual net of processes. The first offers access to many databases hosted in different machines. The casual net includes 90 processes describing the possible dam behaviours taken from published case studies of dam accidents and discussions with experts on dam design and safety. French Power also developed a monitoring system where statistical methods were employed for the data collecting from over 150 dams.

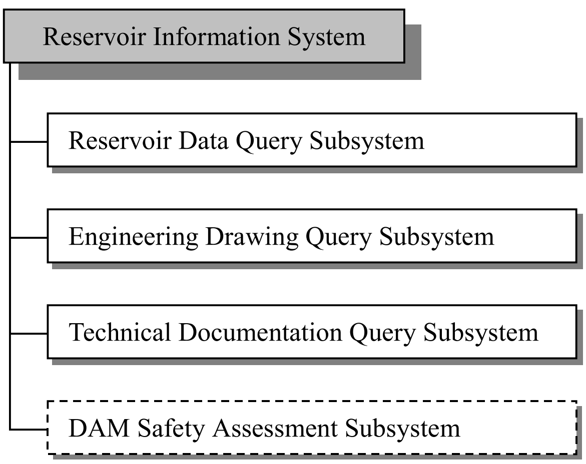

Fig. 2 A schematic figure of the Reservoir Information System

A recent work in this regard is “Expert system for synthesized evaluation of dam safety” by Chinese scientists Wu and Gu [5] who developed an information system with the so-called “one engine and four bases”, that is one inference engine and knowledge, data, method and figure bases. In their system, knowledge base contains the general knowledge of the behaviour of structures, the knowledge of dam designs and that of interpreting examination data. Their database is a collection of construction, design, operating and maintenance records while the method base stores methodology for analysis and the drawings for the purposes of analysis and evaluation are produced by the figure base. This system provides a complete framework for conducting dam safety despite the system has not been fully tested on site.

In Taiwan, Industrial Technology Research Institute (ITRI) has developed “Management Information Systems for Reservoirs in Taiwan” [6] for government and reservoirs authorities in Taiwan. Several analysis programs and mathematical models have been implemented into the system. The systems aim to assist operation and management for 22 major reservoirs in Taiwan and one of the modules is able to identify the state of embankment dams by reasoning from monitoring data. However, the above module is found insufficient for conducting dam safety examination. On the other hand, the RIS system of Sinotech Engineering Consultants, Inc. collects a broad range of construction and design data, technical documents, design drawings and video clips for all reservoirs located in Taiwan. A schematic plot of the RIS of SEC is given in Fig. 2. It has the same functions as those of the information layer in Damsafe and the database in Wu and Gu's expert system. The existing databases in RIS provide solid support for the development of knowledge-based expert system for conducting dam safety assessment in Taiwan, *i.e.* the "DAM Safety Assessment Subsystem" (DAMSAS).

3. The Framework of DAMSAS

A KBES transforms the expertise to data and rules within programs. As shown in Fig. 3, it consists of six major components: knowledge base, inference mechanism, user interface, working memory, explanation and knowledge acquisition facilities. Knowledge base is a pool where domain knowledge is retained. The purpose of inference mechanism is to control the procedures of inference. Temporary facts during the inference are kept in working memory. Knowledge acquisition facility provides an interface for erasing, modifying and inserting knowledge to the knowledge bases. User interface collects inputs from users and displays the outcome of inference by the system while explanation facility aims to supply comprehensive explanation and query functions for users. They can be achieved via HTML, Java, scripting languages and other web computing techniques. Today, most knowledge-based expert systems are developed via specific software tools called shells. Clearly, if the web browsers are used for the user interface and acquisition facility, the problem lies on whether one can find a shell that deals with knowledge base, inference engine, explanation facility and working memory and is fully Internet supported. This is accomplished by using a shell called WebExpert [7] for developing our applications-DAMSAS.

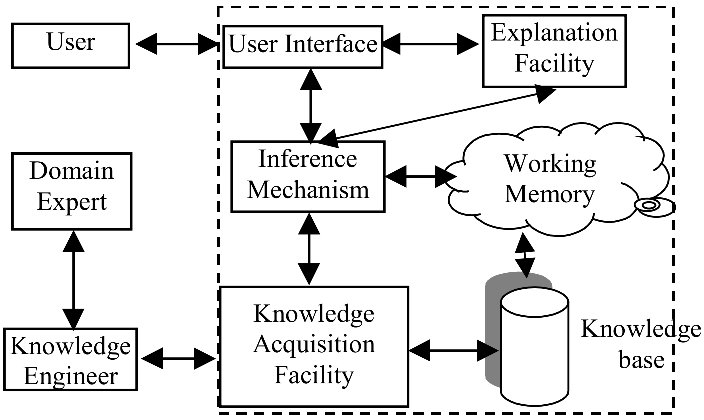

Fig. 3 Illustration of a KBES

This system is currently under development at one of Sinotech servers with Microsoft Window NT Server 4 and Internet Information Server 4. MS Access is used to store the basic data of dams and to hold safety inspection data entered from form elements on the web interfaces. An illustration of DAMSAS is given in Fig. 4. The personnel can use browsers at the client side to execute WebExpert program in the server side via FORM elements. The knowledge engineers and developers can also modify programs and databases via their local editing tools or SQL commands. The programs are indeed a combination of web computing languages including ASP, Javascript and Vbscript.

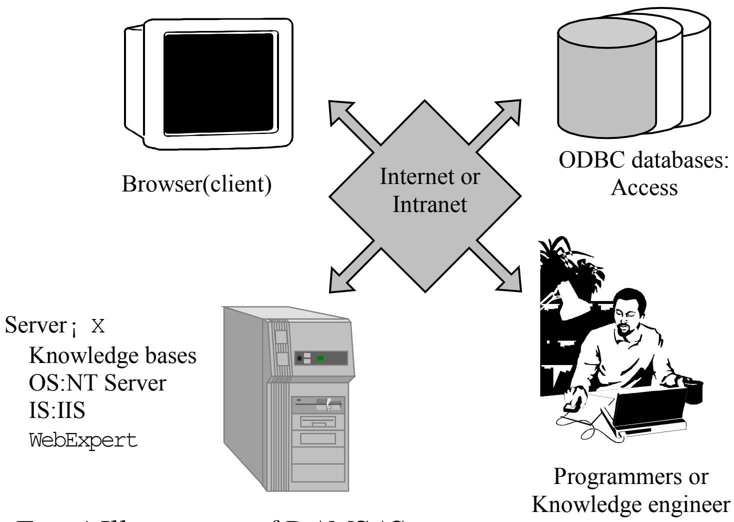

Fig. 4 Illustration of DAMSAS

In Taiwan, the management of dam safety is normally achieved through five types of examination, *i.e.* first filling, regular, maintenance purpose periodical, technical purpose periodical and special inspections. Targeting at the technical purpos periodical inspection which is the most complicated one, the DAMSAS consists of two knowledge bases, *i.e.* knowledge base for monitoring data and knowledge base for visual inspection. The data, facts and methods with respect to the surveillance and interpretation of monitoring data are stored in the knowledge base for monitoring data. The monitoring data are collected from the pre-installed automatic, manual or event-activating monitoring devices within structural components of the reservoirs. Visual inspection is mainly done by experienced staff to conduct on-site examinations on the main and subsidiary components of reservoirs and note any adverse changes and deficiencies in the structures, for example erosion, corrosion, rust, crack, seepage and blockages of drains etc. as well as the conditions and adequacy of monitoring equipment and instruments. The examination personnel generally report their findings on the checklists, inspection forms, sketches and photographs. Depending on the type of dams, the details on the checklists and forms are different from each others to reflect the features peculiar to concrete or embankment dams. In Fig. 5, the facts and data collecting from visual inspection are stored hierarchically with respect to the corresponding inspection items in the knowledge base for visual inspection. The inspection facts consist of six main check items [8] including main dam, auxiliary dam, abutment and reservoir rim, monitoring devices, hydraulic structures and hydraulic machines. Under the main items, there are a number of secondary and subsequent layers of check items. The relations among these items form a very complicate tree with many one to one or one to many mapping.

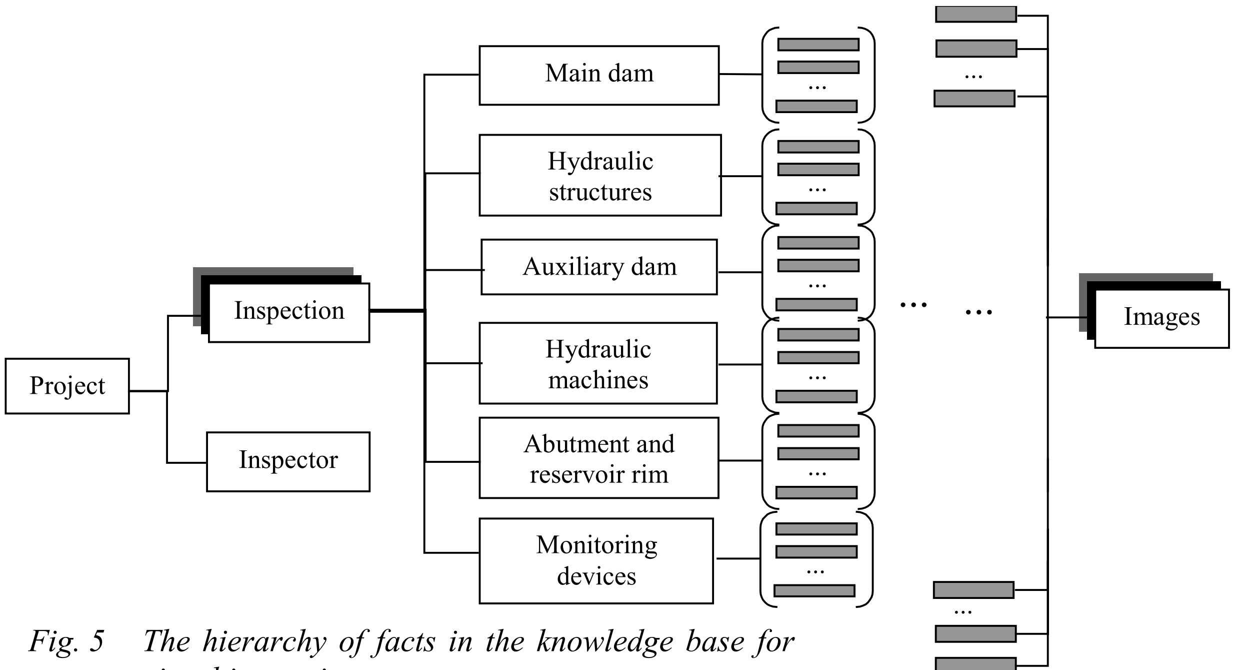

Fig. 5 The hierarchy of facts in the knowledge base for visual inspection

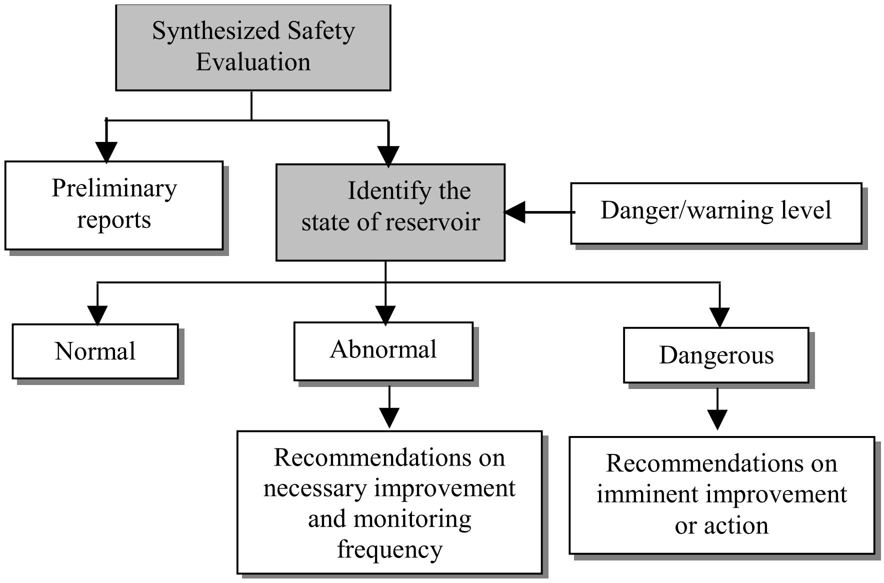

Fig. 6 The results of DAMSAS

These facts are then analyzed and interpreted by the rules and corresponding methods to understand the state of the dams. In order to remain consistent to the current working style of the inspection staffs and engineers, the output of this system would be the state of dams as well as the draft report which contains diagrams, figures, causes and remedial work of the deficiencies observed in the dam inspection. Recommendations are made on the basis of the site investigation and their significance is measured by the weighting system that considers a categories' overall importance as well as its degree within each category. In Fig. 6, a dam is considered in the state of "abnormal" or "dangerous" if the overall score or one of the major categories is above the threshold of "normal". Ten components have been identified on the primary category of weighting system including strength and stability, movement, cracks and joints, seepage, progressive local failure, deterioration, design and construction, threat to normal operation, combined effects of unfavorable factors and overtopping. For every primary factor, there is an corresponding weight depending on the effect of this factor on the safety of dams. The general conditions of dam such as age, capacity, hydraulic height, hazard potential, hydrologic adequacy and seismic zone are also taken into consideration in the weighting system. Based on the field observations, the reasoning for concrete dams cover 16 indicators and 25 indicators for embankment dams [8]. Every indicator represents one finding in visual inspection, for example crack in transverse direction of dam crest. Possible effects and the remedial work for indicators are encoded in the system through knowledge acquisition from experts.

4. Conclusions

This paper presents the use of knowledge-based expert system in the management of dam safety in Taiwan with the purposes of preserving the rules and experience of experienced engineers and personnel on the visual inspection. There are several challenges in building this system such as the resolution of different expert opinions on same examination items during knowledge acquisition, the dynamical creation of images for the web-based system and the preservation of facts and among simultaneous connecting users. The first is overcome by acquiring knowledge from the most experienced expert and implement his/her knowledge to the knowledge base systematically while the others are treated by seeking other tools or programs as alternatives. The application developed in this study is expected to be able to assist the government officials, dam authorities and consultant firms to conduct assessment to identify the state of reservoir safety and provide preliminary suggestions.

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