Case-Based Design for Hydraulic Power Circuit

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Abstract. This paper describes the design and implementation of an automatic hydraulic circuit design system using case-based reasoning (CBR) as one of the successful artificial intelligence paradigms. The domain of case-based reasoning and hydraulic circuit design are briefly reviewed. Then a proposed methodology in automatic circuit design and learning with the use of CBR is described. Finally an application example has been selected to illustrate the usefulness of applying CBR in industrial hydraulic circuit design with learning.

Keywords: Case-based reasoning (CBR), adaptation case, hydraulic circuit design.

1 Introduction

The use of computers in engineering design has become a major trend in industry. Today, different commercial automatic computer-aided design (CAD) software is available to automate the design process in many engineering applications. However, CAD software in hydraulic system design is not as prominent as in many other areas of engineering design. This is mainly due to the complexity of hydraulic analysis and lack of agreement of the most appropriate approach to the design process. In recent years, many researches on intelligent CAD or expert systems for hydraulic circuits have been found in the literature. Most of the CAD systems are built from production rules [1] for design knowledge representation or integrated rule-based and object-oriented technology [2] for reducing the complexity in hydraulic sub-circuit and component representation. Although the approaches are effective, the acquisition and maintenance of rules are the problems facing by not only the software engineers but also the designers using the software. Moreover, static learning[1] is another issue of traditional rule-based systems. To resolve the problems inherited from conventional rule-based expert systems, the AI community proposed another reasoning paradigm called case-based reasoning (CBR). CBR supports learning in the way that new knowledge can be appended to the knowledge base without wider recompilation of the system. This is one of main advantages of CBR that maintenance of knowledge takes much less time. This paper studies the application of CBR in hydraulic system design and a prototype automatic hydraulic circuit design system has been developed to verify this proposed methodology.

[1] Whenever the rules are updated, the whole system has to be recompiled.

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2 Review

2.1 Case-Based Reasoning

CBR [3] is a methodology that allows discovering analogies between a current working situation and past experiences (reference cases). CBR makes direct use of past experiences to solve a new problem by recognizing its similarity with a specific known problem and by applying its solution to find a solution for the current situation. CBR has been used to develop many systems applied in a variety of domains [4, 5, 6, 7, 8, 9, 10], including manufacturing, design, law, medicine, and planning. Basically CBR is constituted with four RE's [3]:

- RETRIEVE — retrieve similar past case matched against current problem
- REUSE — reuse to solve current problem based on solution of past case
- REVISE — revise the past solution if any contradiction occurs when applied to current problem
- RETAIN — retain the final solution along with the problem as a case if the case is useful in the future

When the user inputs a problem, the problem is interpreted and converted as a new case into the specific format of the reasoning system. Then the converted new case enters the stage of RETRIEVAL where the new case is matched against the previous cases in the case library of the reasoning system. In the retrieval stage of CBR usually a simple similarity function is employed to find the nearest neighbor for the current problem from the reference cases. The formula is listed in (1) where w_i is the importance of dimension *i*, f_i^I and f_i^R are the values for feature f_i in the input and retrieved cases, respectively. For symbolic values of *f*, $f_i^I - f_i^R = \begin{cases} 0 & \text{if } f_i^I = f_i^R \\ 1 & \text{if } f_i^I \neq f_i^R \end{cases}$.

$$E(f^I, f^R, W) = \sqrt{\frac{\sum_{i=1}^{n} w_i \times (f_i^I - f_i^R)^2}{\sum_{i=1}^{n} w_i}} \quad (1)$$

2.2 Hydraulic Circuit Design

Hydraulic power is one of power transmission systems and control. It converts mechanical energy to hydraulic energy for producing useful work such as pressing or lifting. The main task of hydraulic power system design is circuit design. The general procedure is shown as follows:

I. The circuit is designed according to the information provided by the client such as maximum operating pressure, maximum load, speed of actuator, duty cycle and application, etc.
II. The sizes of the linear or rotary actuators are determined according to the maximum operating pressure, maximum load and load displacement.
III. Convert the calculated actuator sizes into standard sizes.

IV. The system parameters such as hydraulic oil flow rate, pressure changeover, etc, are determined.
V. The suitable actuator sub-circuits, pump and pump sub-circuit is selected based on the system parameters and the design specifications.
VI. Other hydraulic components used in the circuit are finally selected.

3 Applying CBR in Industrial Hydraulic Circuit Design

In section 2.2 step V, hydraulic engineers are usually accustomed to modify an existing circuit design into a new one for different situation and use. It is because hydraulic circuit design is usually similar even for different situation, so hydraulic engineers have to manually look through many existing effective circuits and then select a similar and suitable one and perform modification.

The process is repetitive and tedious in the stage of retrieving, because engineers have to review the circuits one by one. However, the process of the retrieving an existing circuit and adapting it to fit better the current situation can be strongly supported by CBR. If the existing circuits are collected in a computer database (case library), and each circuit is stored along with its functional and application-specific requirements of the outputs, these parameters can serve as the case (circuit design) indexes. Whenever the hydraulic engineer wants to retrieve a past case from the case library, he just needs to input the functional and application-specific requirements, and CBR uses (1) to calculate the most similar past case. If the engineer is not satisfied with the recommended case, then the next most similar past case would be shown. This could be done because the cases are already ranked with different similarity level in the calculation of case similarity.

After that, the engineer could adapt or modify the retrieved case manually by the above procedure or by applying the adaptation rules supplied by CBR. Those adaptation rules are specific production rules captured from experts or from the engineer's own experience. Finally the engineer can decide if the case is good enough to store into the case library for future use.

Hydraulic circuit designs differ by not only the circuit diagram but also the functional attributes along with them. For circuit adaptation, if some components are replaced, then the attributes will also be modified by inserting or deleting some of them. CBR enables structural modification of cases, so that attributes can be added or deleted accordingly. For example, an engineer retrieves an past case and performs modification on the circuit design, then the number of attributes would be changed according to, which sub-circuits are revised by adding predefined attributes or deleting unnecessary attributes in the sub-circuits.

4 Application Example

The system implemented is able to recommend most similar circuit design based on the circuit specification. The working environment and front-end user interface of the circuit design system are shown in Fig. 1. The learning ability of the system is illustrated in this part with the aid of an example. Table 1 shows partial attributes of the case representation for a hydraulic sub-circuit shown in Fig. 2.

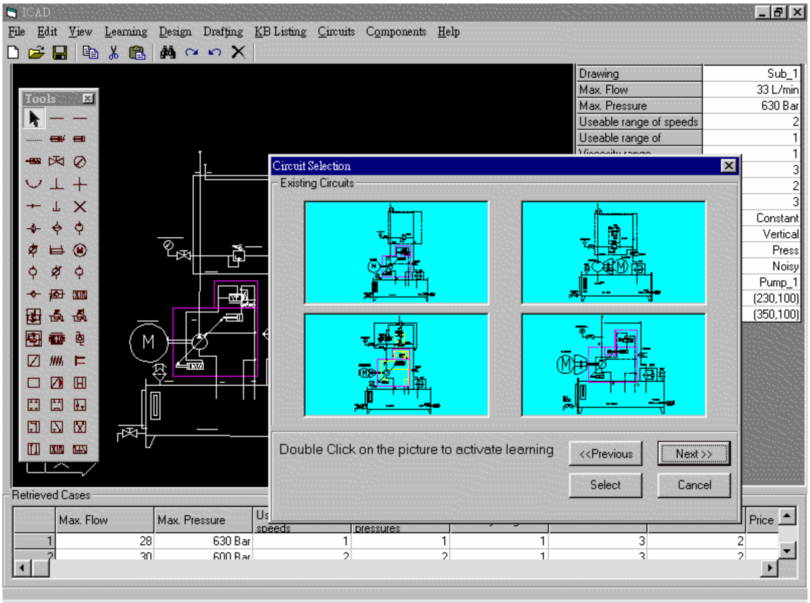

Fig. 1. Working environment and front-end user interface of the circuit design system

Table 1. Partial attributes of a hydraulic sub-circuit

Drawing name	Var_1
Max. Flow	33 L/min
Max. Pressure	630 Bar
Variation steps of speed	2
Variation steps of pressure	1
•	•
•	•

Whenever a past similar case is retrieved, the case is adapted in order to reuse it for current situation. However, not every case is adaptable by the system, as the adaptation rule set of any system is always incomplete. At this moment, the user intervention is necessary to compensate the inability of adaptation of the system. The users will adapt the case using his domain expertise. In order to learn the domain knowledge from the user, the operation performed by the user is recorded by means of answering questions in step. When a user wants to adapt a case, the system will ask the user which kind of operations to perform. Once the user has chosen the operation, the corresponding actions are supplied to the user to choose. In recording the operations, the system can learn from the user the adaptation knowledge. The learnt knowledge is encapsulated as a case called *adaptation case* because it is used to guide adaptation. Subsequently, when similar problem case arises, the system will become capable to handle the adaptation by referring to the adaptation case.

4.1 System Implementation for Learning

Initially, the existing standard block drawings of hydraulic sub-circuits have been constructed along with their respective attributes such as the one listed above. In the training stage of the system, a list of preview of existing drawings is shown. The user can select a parent sub-circuit to derive a new circuit. For instance, consider the above example again. If the user changes the attribute “Max. Flow” from 33 L/min to 350 L/min, the pump component of the parent sub-circuit has to be replaced with a new one that is able to support flow rate of 350L/min. This is learnt by means of the production rule supplied by the user:

if “Max. Flow” <= 33L/min then use old_block else use new_block

The system can keep all of these production rules to adapt the future cases. Whenever a sub-circuit has maximum flow rate greater than 33L/min, it has to select a certain pump component. Because of the change of the pressure relief valve component, a larger size pressure-relief valve symbol should be inserted in the sub-circuit as shown in Fig. 2. The change of drawing could also be done by the system integrated with AutoCAD platform.

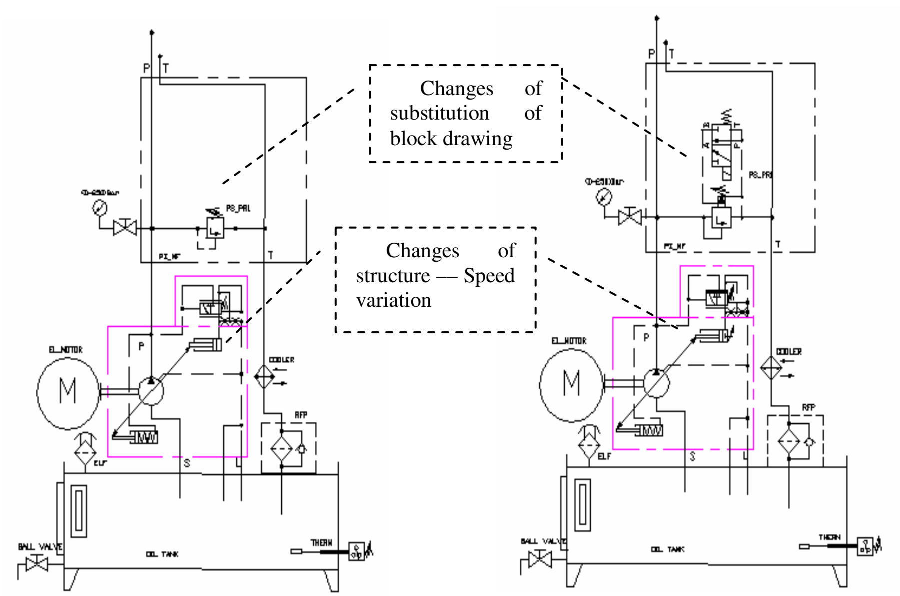

Fig. 2. An example change of components recommended by circuit design system using CBR

4.2 Design Example and Discussion of Results

The input specification for an example of a 110-ton horizontal hydraulic wooden squeezing station is shown in Table 2. Owing to no standard solution in the circuit design, so design evaluation will be concentrated on the validity of the design. The results generated from the prototype circuit design system have been verified to perform in accordance with the stipulated specifications by the experts from two leading hydraulic engineering companies. The major contribution of this circuit design system is the reduction of design lead time. Non-experts normally spend three or four days to finish a circuit design. The major difficulty in manual design is to find appropriate components and connection among components. It is because of the lack of universal design theory, hence finding and understanding the properties of components in a circuit is a very time-consuming task, even for experts. With CBR, many past circuits can be reused and the time for re-considering the selection of components satisfied by the circuit specification can be saved. The remaining effort for a circuit design is how to adapt an existing circuit into a new suitable one and this work is much simpler than designing a brand new circuit from scratch.

Table 2. The input specifications of a 110-ton horizontal hydraulic wooden squeezing station

Attribute	Value
Actuator group no.	1 (Ram cylinder for squeezing)
Maximum loading (Ton)	100
Stroke length(mm)	300
Max. stroke speed (mm/sec)	30
Max. speed for squeezing (mm/sec)	10
Mounting method	Front and rear flange
No. of variation stage of the load pressure during squeezing	1
Type of control in squeezing action	Position sensing
Stage of the actuator speed	Two
Acceptable noise level	60 db
Expected service life time	5 years
Machine operating hours/day	12 hours/day
Prime mover rated speed	1450 rpm
Maximum system operating pressure	210 bar

5 Conclusions

CBR is a methodology in AI that can substantially support decision-making process of human beings. The most important part of CBR is to reuse past experience in current problem so that identical parts of the current problem can be directly reused while only similar and missing parts of the problem can be solved by analogy using expert adaptation rules. This work is a new attempt of applying CBR methodology in building a hydraulic circuit design system with learning capability. The circuit design system can dramatically reduce the unnecessary time consumed for repeatedly designing similar hydraulic circuit by reusing past cases. Moreover, program recompilation is unnecessary for modification of circuit knowledge base due to the learning ability of CBR. A prototype automatic design system for industrial hydraulic control circuits has been built using the recommended methodology and it has been verified to work successfully.

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