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A modularized case adaptation method of case-based reasoning in parametric machinery design

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ABSTRACT

Case adaptation is fundamentally to successfully applying case-based reasoning (CBR) in parametric machinery design, and support vector machine (SVM)-based adaptation is a promising method for CBR adaptation. But the standard formulation of SVM can only be used as a univariate modeling technique due to its inherent single-output structure, which result in the construction of different SVM-based adaptation engine for each solution element adaptation, and such engines could ignore the effects of the mutual parameter relationships for the adaptation results. This paper focuses on the multivariable adaptation problem in CBR adaptation, and proposes a modularized adaptation method by integrating with multiply relational analysis, case parameter clustering and adaptation engine construction. Firstly, the hidden parameter relationships between problem and solution (P–S), problem and problem (P–P), and solution and solution (S–S) parameters are extracted from old cases, then these parameters are clustered into several parameter clustering (PC) modules in terms of their internal relationships. Finally, multi-output SVM (MSVM) is used to build the adaptation engine for each PC module. This method not only improves the performance of SVM-based adaptation by utilizing the mutual parameter relationships, but also reduces the computational expense of MSVM-based adaptation by partitioning the only one adaptation engine into several sub-engines. Actual design examples are introduced to illustrate the process of modularized adaptation, and the empirical experiments in the different examples are carried out to validate the superiority of our proposed method. Through comparing the adaptation accuracies with those provided by other classical neuro-adaptation methods, the modularized adaptation is proved to be a feasible method for case adaptation.

1. Introduction

Parametric machinery design (PMD) based on case-base reasoning (CBR) is widely used in industrial domain for rapid machine development (Ercan and Elias-Ozkan, 2015; Yu et al., 2015), as the ability to develop new mechanical products within a short period of time is key to the survival and success of mechanical companies. Instead of designing everything from scratch, with the help of CBR methodology, machinery designers can determine the parameter values of new mechanical product by reusing previous successful solutions to current numerical problem (Reyes et al., 2015; Hashemi et al., 2014; Li and Xie, 2013)[p]. To support this, the existing product is considered as a design case represented by problem and solution parameters, and the PMD-CBR system acts as knowledge-based system which solves new problems by matching the problem values and adapting the solution values of similar design case, as the old solutions of retrieved cases cannot be applied directly to the new problem under normal circumstances (Nouaouria and Boukadoum, 2013). However, existing commercial PMD-CBR systems are generally characterized by a sophisticated case retrieval mechanism without a well developed case adaptation engine (Jalali and Leake, 2016; Fuchs et al., 2014), and the solution values of most similar case is modified by decision-maker to fit the new problem, which heavily depends on human subjective judgment. The lack of case adaptation engine is due to the fact that case adaptation generally needs to be guided by some organized form of domain knowledge, while adaptation knowledge is not always accessible and available.

To alleviate the knowledge acquisition burden for case adaptation process, the concept of knowledge-lean adaptation has been proposed (Mitra and Basak, 2005), which employs the knowledge already contained inside the CBR system and its components to reduce the engineering effort needed for the acquisition and organization of adaptation knowledge. Recently, various machine learning (ML) methods are applied to perform automatic knowledge-lean adaptation such as genetic

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algorithm (GA) (Zhang et al., 2015; Liao et al., 2012; Passone et al., 2006), neural networks (NN) (Zhou et al., 2014; Henriet et al., 2014; Butdee, 2012), support vector machine (SVM) (Qi et al., 2015; Sharifi et al., 2013), simulated annealing (Liu et al., 2012), and decision tree (Qi et al., 2012). ML-base adaptation explores the utilization of inductive learning to acquire adaptation knowledge from old cases and applies the acquired knowledge to implement automatic case adaptation. Among above-mentioned MLs, SVM has been successfully proved to be superior to classical NNs in solving classification and regression problems (Sakr and Elhajj, 2013; Zhang et al., 2013; Gryllias and Antoniadis, 2012; Chuang and Lee, 2011), and some studies have employed SVM for case adaptation with various degrees of success (Qi et al., 2015; Sharifi et al., 2013).

However, until now, SVM in case adaptation have not been widely employed. This is because the standard formulation of SVM can only be used as a univariate modeling technique due to its inherent single-output structure (Qi et al., 2015). Consequently, the studies of SVM-based adaptation have to construct different adaptation engine for each solution parameter separately, which ignore the effects of the mutual relationships among problem and solution parameters for the adaptation results. Although some studies tried to use various optimization approaches, such as particle swarm algorithm (Ziani et al., 2017), fruit fly optimization (Ding et al., 2016), integrated GA (Zhang et al., 2015), artificial immune algorithm (Aydin et al., 2011) and simulated annealing (Lin et al., 2008), to improve the performance of SVM model, how to generate more solution adapted values simultaneously is still urgent for SVM-based adaptation research. An alternative method is to revise the structure of SVM to support multiple output, and the multi-output SVM (MSVM) proposed by Pérez-Cruz et al. (2002) is a possible candidate one, and MSVM has been successfully applied to several multivariate output situations (Tian et al., 2015; Bao et al., 2014; Xiong et al., 2014) also introduced firefly algorithm to optimize the MSVM. However, for large size of design case which has large numbers of parameters, one MSVM-based adaptation engine for all solution parameters could still result in the rapid increase of computing cost and the reduction of adaptation efficiency.

Taking into account the individual-oriented adaptation by SVM and the whole-oriented adaptation by MSVM, this study concentrates on the numerical parameterized adaptation, and proposes a new multivariable output adaptation method. It is realized by integrating with multiple relational analysis, case parameter clustering and adaptation engine construction. Firstly, the hidden relationships among problem and solution parameters, including problem and solution (P–S), problem and problem (P–P) and solution and solution (S–S), are extracted from case base, then these parameters are clustered into several parameter clustering (PC) modules in terms of their internal relationships. Finally, a MSVM-based adaptation engine is built for each PC module. The related works will be discussed in the following sections, and the paper is structured as follows. Section 2 gives a brief review of knowledge-lean adaptation and presents the motivation of this research. Section 3 makes specification on proposed method. Section 4 gives two examples to illustrate the procedure of the proposed method. And an empirical experiment is provided to make a comparative analysis in Section 5. Section 6 makes conclusions.

2. Research background

2.1. Knowledge-lean case adaptation method

Different from knowledge-intensive adaptation methods, such as substitution method, transformation method and ranking method (Mitra and Basak, 2005), which require sufficient programmable knowledge for case adaptation, knowledge-lean adaptation methods take advantage of the knowledge of CBR system itself. The design of knowledge-lean adaptation algorithm is ideally independent of the domain knowledge, or very little domain knowledge is required. Early studies of knowledge-lean adaptation adopted statistical ways, e.g., the closet analogy, the median, the equal mean and the weighted mean, to calculate the average of the solution values of retrieved cases. Although these statistical methods are effective in some situations (Qi et al., 2016), limitations on precision also exist due to the fact that the information of retrieved cases has not yet been fully utilized (Hu et al., 2015). Some studies (Jarmulak et al., 2001) acquired the adaptation rules by analyzing the differences between cases and their corresponding solutions, and identifying, if possible, a plausible difference pattern. However, the difference pattern is limited to simple case adaptation with few parameters. Later, some researchers combined ML methods into knowledge-lean adaptation to construct different adaptation engines. A recent overview in knowledge-lean adaptation based on ML is given in Qi et al. (2015). Among them, neuro-adaptation (i.e., NN-based adaptation) is a typical knowledge-lean method. However, classical NNs have some inherent drawbacks, e.g., the poor performance for high number of attributes, the problem of multiple local convergence, and the danger of overfitting.

SVM-based adaptation is a new knowledge-lean adaptation method, and it has been proved by Qi et al., (2015) that it is a feasible alternative for neuro-adaptation. The reason is that, comparing with NNs, SVM implements the structural risk minimization principle and tries to minimize an upper bound of generalization error instead of minimizing the misclassification error or deviation from correct solution of the training data (Tay and Cao, 2002, 2001). So SVM could achieve an optimum network structure, and eventually result in better generalization performance for data set with a large number of attributes. Meanwhile, the solution of SVM is a global optimum, and overfitting is unlikely to occur with SVM. But the standard formulation of SVM can only be used as a univariate modeling technique for CBR adaptation due to its inherent single-output structure, which result in the construction of different SVM-based adaptation engine for each solution parameter. So more efficient multivariate adaptation way is urgent for SVM-based adaptation, and it is also our research objective in this paper.

2.2. Motivation and originality of this research

As mentioned in Section 1, an alternative way to improve the performance of SVM-based adaptation is to utilize the MSVM which is a multi-input and multi-output structure. In MSVM-based adaptation engine, the input vector includes the difference values of problem parameters between training case and target problem, and the solution values of training case, while the output vector is a group of new solution values for target problem. For large size of case with large numbers of problem and solution parameters, it could drastically reduce the efficiency of single MSVM engine. So it is meaningful to put forward a new adaptation method whose adaptation granularity is between the cell-level of SVM-based adaptation (i.e., one adaptation engine outputs one adapted solution value) and the system-level of MSVM-based adaptation (i.e., one adaptation engine outputs all adapted solution values).

Inspired by that, this paper intends to introduce a modularization technique into CBR adaptation, and the new adaptation engine is performed at modular-level, i.e., one adaptation engine for one clustering module, and the clustering module contains some problem and solution parameters which have strong relationships. A relational matrix can be used to represent these relationships, whose entry is the relational value between corresponding parameters. Our previous study (Hu et al., 2015) has adopted gray relational analysis (GRA) to analyze these implicit parameter relationships. Due to the relational matrix, a matrix-based modularization (MBM) method is suitable for our modularized adaptation method to group different problem and solution parameters together. Then, MSVM-based adaptation engine could be constructed for each PC module. In a word, our paper will dedicate to integrate the relational information of case parameter into MSVM to facilitate efficient case adaptation in application of PMD-CBR, and the empirical data are collected to compare the adaptation performance of modularized adaptation with that of classical neuro-adaptation methods.