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Self-adjusting multidisciplinary design of hydraulic engine mount using bond graphs and inductive genetic programming

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ABSTRACT

This paper presents a novel approach in multidisciplinary design of mechatronic systems, using an inductive genetic programming (IGP) along with a bond graph modeling tool (BG). The proposed design algorithm dynamically explores the space of finding optimal design solutions through utilizing two navigated steps for simultaneous optimization of both topology and parameters. In the first step, an IGP tool is applied on the bond graph embryo model of the system for topology synthesis. In the second step, an optimization tool that incorporates an artificial immune system (AIS) is implemented for optimization of the parameter values. A supervisory loop statistically analyzes the efficiency of the different mechatronic elements in improving the system's performance. By acquiring knowledge and learning from prior trials, the evolution parameters are automatically and dynamically adjusted, with the aim to achieve more efficient evolution progress. The developed method is practically compared with an available bond graph-genetic programming (BGGP) method via designing an aerospace engine mount system. Results show that more navigated and accurate design results are acquired from the proposed method.

1. Introduction

With the advent of new technologies, many real engineering systems have become complex and multidisciplinary. The mechatronics is described in some literature as the cooperative application of mechanics and electronics in designing intelligent electromechanical products controlled by digital computing circuits via controller software (de Silva, 2005; Behbahani and de Silva, 2007). Traditional optimization tools do not satisfy designers in designing complex systems. It has been demonstrated that the design process of mechatronic products should be shifted from a single-disciplinary sequential strategy to a multi-disciplinary integrated and concurrent approach (Behbahani and de Silva, 2008).

Recently, considerable research has been conducted on how to shift the design duties performed by a human expert designer (topology realization in particular) to an automated algorithm. Researchers are eager to develop intelligent methods, capable of simulating human intelligence in design procedure. A new set of tools has been recently developed to help in achieving this goal, which mostly utilizes soft computing methods. Soft computing is a phrase applied to particular methods which imitate human intelligence with some human-like capabilities such as learning, reasoning, and decision making.

To optimally design a mechatronic system, both its topology and parameter values should be optimized concurrently. To handle this requirement, some research activities have been performed in development of engineering design optimization tools through a combination of GP and physical modeling tools. A notable tool in this regard was suggested by Koza et al. (2000). They presented a uniform approach for the automatic synthesis of both topology and size of various electrical engineering problems. Inspired by Koza's work, an integration of bond graph (BG) modeling and GP was introduced by Seo et al. (2003). They introduced several BG construction functions, which were presented in an extendable tree-like structure. Each tree-like structure was applied on the embryo to generate an individual solution with a new topology and size by means of GP. Wang et al. (2005) have provided a different approach to synthesize the topology and size of a mechatronic system, using integration of BG and GP. In particular, they used the developed tool for controller synthesis, using the concept of controller design in physical domain. Later, Behbahani and de Silva (2007) extended the bond graph-genetic programming (BGGP) integration for synthesis of non-linear mechatronic systems and used it as a black-box non-linear system identification tool.

In 2013, Behbahani and de Silva argued that in autonomous synthesis of a mechatronic structure, topology synthesis and parameter realization should not be treated in the same level of

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optimization. They developed a two-loop mechatronic design tool by using a hybrid of GP and simple GA, integrated with BG modeling tool. Recently, they incorporated the concept of niching optimization in the evolutionary mechatronic tool, in which instead of one solution, several elite configurations with considerable topological differences were presented to the human designer. This method is more compatible with the nature and requirements of topology design.

In utilizing the above tools for solving a design problem, the designer generally needs to run the design tool several times and roughly adjust the evolution parameters, based on the performance assessment of the tool in handling design criteria with the aim to push the solutions toward the optimum solution. In the present work, the utilized tools in both topology and parameter value optimization steps are enhanced via incorporating learning and intelligent dynamic adjusting schemes in a supervisory loop – a task which is traditionally accomplished by the human designer.

The current paper presents a novel design tool by integration of bond graphs (BG) and inductive genetic programming (IGP) for guiding automated topology synthesis. The method and its related tool are therefore named BGIGP. The tool utilizes the superior modeling capabilities of BG, along with the valuable search and optimization features of IGP. In fact, IGP evolves the BG model of the solution of a specific problem to achieve optimum fitness function. This research extends the set of researches (Seo et al, 2003; Behbahani and de Silva, 2006, 2013), which introduces the BGGP method. Unlike the prior work, utilized optimization tools in this work are able to dynamically adjust their parameters. In fact, a dynamic self-tuning algorithm is developed in order to navigate the design process to the neighborhood of the optimum solution, through a supervisory loop and to explore that region more efficiently.

In an inner loop, an artificial immune system (AIS) tool takes care of the optimization of the inherited parametric values of the elements of each generated topology. It means that the fitness function of the elite of each generated topology is considered in the competition with other topologies, by calculating its fitness when rather optimum numerical values are assigned to its parameters. This prevents the possibility of losing a good topology due to having inappropriate numerical parameters.

Another novelty of the present paper is knowledge extraction from the optimization process, which is performed in a supervisory loop. The extracted knowledge is utilized for upcoming execute cycles of the optimization for the problem in hand, as well as for solving new problems. It should be noted that not only multi-domain, but also single-domain engineering systems can be optimally evolved via BGIGP method.

As the case study of the present paper, a BG model of a typical engine mount is introduced and its topology is evolved via IGP, while its parametric values are optimized by AIS. The obtained results are compared with the results of BGGP.

The paper is organized as the following. After the introduction, a general statement of the problem and the scheme of design flowchart are presented. The subsequent sections discuss the background theory of BG, IGP and AIS in order. In the following, the developed design methodology is compared with BGGP, the case study of an engine mount design is presented. In the concluding section, the main contributions are summarized and respective conclusions are provided.

2. Design flowchart

Fig. 1 presents the flowchart of the proposed mechatronic design method. Its main objective is to develop the structure (i.e., topology and parameters) of a mechatronic system automatically from an initial design to a very detailed one. In the initial problem definition, the design goals and constraints (such as frequency response function, time response specifications) and design parameters (such as dimension and available mechatronic elements) are specified.

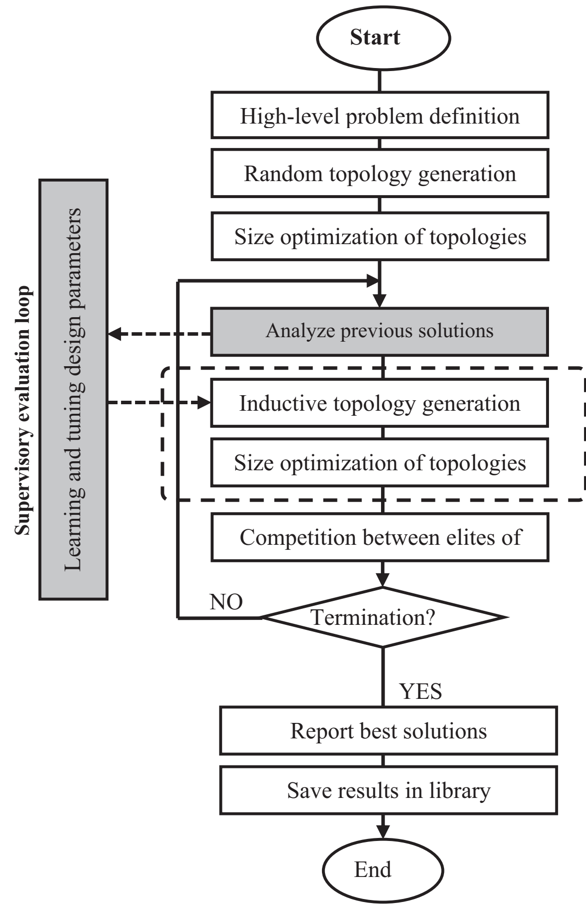

Fig. 1. Schematic design flowchart.

In this design procedure, like all other evolutionary algorithms, the first generation of the individuals (in the topology level) is created by adding random combinations of the elements to the embryo. In the next step, after counting the required parametric values, an AIS-based algorithm automatically optimizes parameter values of each randomly generated topology to find its elite representative (i.e., inner loop of the optimization). The elites of different topologies compete with each other to participate in creation of the next generation of topologies. This process of evolutionary optimization of topology and parameters is continued until the termination conditions are satisfied and the best solution is eventually given to the designer.

A supervisory system evaluates the performance of the design process. It analyzes the type and the number of the mechatronic elements (such as resistance, inductance, capacitance, and the sources of effort) in the BG model. This loop is employed to learn from the statistical analysis and subsequently to dynamically adjust the topological design parameters. In prior work, a new generation is evolved randomly and optimistically so which the evolutionary algorithm keeps the good genes of a solution and removes the weak parts. Implementation of the guided IGP method increases the possibility of exploring topologies around the global optimum.

3. Integration of BG and IGP

BG with graphical representation is proved to be an effective modeling method for multi-domain systems with lumped parameters