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Automated synthesis of passive analog filters using graph representation

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ABSTRACT

In this paper, a novel method based on graph encoding scheme and clone selection algorithm is proposed for synthesizing passive analog filters. Graph is the most natural and convenient data structure to represent analog electronic circuit. The proposed graph-based encoding scheme can represent any topologies of passive analog circuit and their component values. Combined with the efficient analog circuit encoding scheme, clone selection algorithm is employed as a search engine for automatic design of passive analog filters. The proposed method can synthesize both topology and sizing (component parameters) of circuit simultaneously. Three filter design tasks are experimented to evaluate the proposed method. The experimental results demonstrate that passive analog filters can be generated effectively with modest computation time. Taking more practical conditions into account, the proposed method can be applied into automatic design of passive analog filters for engineering application without the guidance of experienced engineers.

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1. Introduction

Automatic design of electronic circuit is the dream of electronic engineers. Many scholars have done a lot of research on this direction. Until now, automatic design of digital circuit has made great progress. However, analog circuit synthesis, including topology and sizing, is more complex than digital circuit synthesis. Most of analog circuits are designed by skilled engineers. They usually use conventional methods which are based on domain-specific knowledge. However, most of engineers are often strongly constrained by their limited domain knowledge. Fortunately, recent significant development of computer technology and circuit theory makes it possible for us to take some new approaches to automatically synthesize analog circuits.

Analog circuit synthesis involves both the sizing (component value) and topology (circuit structure) optimization. Recently, remarkable progress has been made in analog circuit synthesis. Evolutionary methodologies based on different encoding schemes were compared by Zebulum, Pacheco, and Vellasco (1998). Comparison of constrained and unconstrained evolutionary methods for LC low-pass filters was done in Sapargaliyev and Kalganova (2006).

The main aspect determining performance of evolutionary analog circuit synthesis methods is circuit encoding scheme. A good circuit encoding scheme should be provided with the following properties. First, encoding scheme should be able to represent any circuits (including circuit topologies and component values), so that algorithm is able to generate some circuits which satisfy design demands. These generated circuits usually are totally different from the ones designed by conventional design methods. Second, the complexity of algorithm which converts the encoding to circuit should be as low as possible so that large computation time will be saved. Third, encoding scheme should be syntactical closed, so that validity of circuits would be maintained during the evolutionary process. Until now, according to different encoding schemes, methods for automatically designing passive analog filters are mainly classified three categorizations, namely, string based methods, tree based methods and graph-based methods.

1.1. String based method

Horrocks successfully applied genetic algorithm (GA) into component value optimization for passive and active filters using preferred component values (Horrocks & Khalifa, 1996; Horrocks & Spittle, 1993). GA was also applied to select circuit topology and component values for analog circuit by Grimbleby (1995).

Analog genetic encoding (AGE) was proposed to synthesize analog electronic circuits (Mattiussi & Floreano, 2007). The AGE genome is composed of string of characters, which characters denote different meanings such as device names and parameters. Each gene of AGE genome denotes a device, in which two regions are included for denoting each terminal and parameters of the device,

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respectively. In decoding process, all devices are extracted from genome. Connection of these devices is determined by device interaction map. Final circuit is constructed by connect all devices step by step according to device interaction map. The experimental results verify that AGE can synthesize analog electrical circuit. However, the encoding scheme is so complex that much computation time will be taken during decoding process.

Lohn and Colombano developed a compact circuit topology encoding scheme that decreases complexity of evolutionary synthesis of analog circuit (Lohn & Colombano, 1999). This encoding scheme restricts some potential topologies so that running time is decreased. Based on the topology-restricted encoding scheme, parallel genetic algorithm is used to synthesize analog circuits, in which circuit size, circuit topology, and component value are evolved (Lohn & Colombano, 1998).

1.2. Tree based method

Koza and his collaborators have done lots of research on automatic synthesis of analog circuits by means of Genetic Programming (GP) (Koza, 1992; Koza, Bennett, Andre, Keane, & Dunlap, 1997). It may be the most notable progress in this field. They developed circuit-construction program trees to represent analog circuits. Using GP method, analog circuits are evolved to the best ones until stop criteria is reached. Performance of each circuit is evaluated by SPICE (Simulation Program with Integrated Circuit Emphasis) simulation program. A main drawback of this technique is that it is very complex to implementation and it requires huge computing time.

In Chang, Hou, and Su (2006) and Hou, Chang, and Su (2005), a novel tree based encoding scheme was proposed to synthesize basic RLC filter circuits using GP. Compared with general-topology method, this approach is more efficient for passive circuit synthesis. However, this representation method rigorously restricts circuits as series-parallel topologies so that diversity of structure of passive analog filters decreases significantly.

1.3. Graph-based method

In original GP system (Koza, 1992), genotype is the Parse tree of LISP language. Koza et al. used tree structure to solve complex problems even though these problems can be represented as graphs, i.e. synthesis of electronic circuits and controllers. In fact, graph itself is an important data structure which can represent complex problems. Although there has been few researches using graph-based encoding scheme to synthesize analog circuits, graph has been employed to represent complex structures. Teller and Veloso (1995) have introduced graph-based genotype into GP. In their works, directed graph was used to represent complex problem. In order to solve complex problems, another GP, linear-graph GP, was proposed by Kantschik and Banzhaf (2001). Each program in linear-graph GP was represented as a graph. Each node of the graph contains a linear program and a branching node. Linear program will be executed from node to node; the sequence of execution was specified by the directed arcs. A detailed description of linear-graph is found in Kantschik and Banzhaf (2002).

Kitano (1990) and Boers and Kuiper (1992) firstly presented grammar based encodings for designing structure of neural networks. They use Lindenmayer-systems (L-systems) (Lindenmayer, 1968) to describe the morphogenesis of linear and branching structures in plants. L-systems apply a set of production rules to rewrite a starting string into a new string in parallel. By interpreting the terminal symbols in string, a graph is obtained from this string. Luerssen (2005) used collective hyper graph grammars to encode and evolve cell automata networks, and successfully applied this method into symbolic regression and design of neural network architectures. In additional, Globus, Lawton, and Wipke (1999, 2001) used graph to present molecular structure, and applied GA to automatically design molecular.

A graph adjacency matrix encoding scheme was proposed to represent electronic circuit topology (Mesquita, Salazar, & Canazio, 2002). The performance of this method is evaluated through synthesizing several filters. It is shown that this method significantly reduces the number of anomalous circuits generated by genetic operations. As it is unable to represent three terminal elements in adjacency matrix, this encoding scheme is only suitable to synthesize high level circuits whose basic units are functional blocks such as operational amplifier (Mesquita, 2002).

An evolutionary graph generation (EGG) system (Chen, Aoki, Homma, Terasaki, & Higuchi, 2002; Homma, Aoki, & Higuchi, 2003) was proposed to synthesis digital circuits. This system is also applied into synthesis of analog circuits (Natsui, Homma, Aoki, & Higuchi, 2004). In EGG, *node* is used to represent device or I/O pin, and *edge* is used to represent connection between devices and I/O pins. Individuals are represented as graph. Some evolutionary operators are designed to modify individuals through directly changing graph structure. In this system, Crossover and mutation are main operators. They might destroy graph structure of individuals so that validity of individuals is not guaranteed during evolution.

As mentioned above, most of automatic design methods use string or tree represent analog electronic circuits. However, structure of electronic circuit essentially is cyclic graph. When GA or GP is applied to circuit synthesis, a mapping between encoding scheme of electronic circuit (string or tree) and electronic circuit (cyclic graph) should be established. It needs quite complex mapping rules to translate circuit encoding into circuits, and vice verse. Most of existent automatic synthesis approaches either use topology-restricted methods (Chang et al., 2006; Lohn & Colombano, 1999) or use too complex mapping rules (Koza et al., 1997). Although many researches have been done on circuit representation using string or tree, few attention have been devoted to a direct representation in which cyclic graph structure is used to represent electronic circuits. Such a direct representation is very useful to automatically synthesize analog electronic circuits. It can represent any circuits and use quite simple mapping rules.

In this paper, a novel paradigm was proposed to synthesize analog passive filters from two aspects (topology and sizing of passive analog filters) by using a novel graph-based encoding scheme and clone selection algorithm. In the proposed graph-based encoding scheme, nodes are used to represent connection of components, while edges are used to represent components. No matter what type components are, it only needs two-terminal edges to represent all components, which makes modification to circuits much easy, so that efficiency of the algorithm for synthesizing filters can be improved. In addition, some powerful operators are designed to provide modification of candidate circuits during evolutionary process. These advantages make our search algorithm more efficient to traverse search space.

Based on high efficient circuit encoding scheme and powerful search engine—the clone selection algorithm, the proposed approach can automatically and efficiently synthesize passive analog filter. Taking more practical conditions into account, this approach can be used in engineering implementation.

The remainder of this paper is organized as follows. In Section 2, the graph-based encoding scheme for passive analog circuit is explained in detail. A clear depiction of six operators for modification of candidate circuits in evolutionary process is also provided. In Section 3, a novel paradigm for synthesizing passive analog filters using graph-based circuit encoding scheme and clone selection algorithm is clearly described. The experiments of a low-pass,

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