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Designing Optimum Multi-Domain System by Integrating Bond Graph and Genetic Programming

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ABSTRACT: Integrated modeling of multi-domain physical systems requires a common language. One of the methods which has been used to do so is called the bond graph. The bond graph provides a common and core language for describing basic elements and connections across different fields by using its elements, bonds and junctions. Also, by using genetic programming as an evolutionary method, an initial model can be evolved into a final model. The initial model of a system in a bond graph called Embryo and must have input, output and basic elements of the desired model. By defining a series of operational functions in genetic programming, an embryo model evolves and a final model obtained in one objective and multi-objective approaches. The current research presents an optimized design tool by the integration of a bond graph and a Pareto multi-objective genetic programming for guiding automated topology synthesis. In order to evaluate the performance of the proposed method, obtained results were first compared to the 20-sim software and then two models of electric filter and a mass, spring and damper system compared to the reference.

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1. INTRODUCTION

Modeling of multi-domain systems needs a common language. The bond graph is one of the methods which had been used widely last years for modeling of the different type of systems. Bond graph introduced by Karnopp and Rosenberg in 1968 [1]. Some researchers used this method for modeling mechatronic systems. Louzazni et al. [2] used the single and double diode models to represent an equivalent circuit of the photovoltaic generator and obtain its model via a bond graph modeling method. In order to create an explore multi-domain design space, Genetic Programming (GP) can be used. GP first proposed by Koza in 1992 [3]. Jamali et al. [4] used the multi-objective genetic programming method for modelling of a complex non-linear process. Rosenberg et al. [5] present an automated procedure that can explore the mechatronic design space by integrating bond graph and genetic programming. Samarkoon et al. [6] use the one-objective approach of integrating bond graph and genetic programming for designing electrical filters, a mass, spring and damper system and an industrial fish processing machine.

In this research, a two-step optimization approach for integrating bond graph and genetic programming presented. Also, multi-objective Pareto design concept applied to the proposed method to design new topologies with both lowest complexity and lowest absolute error.

2. INTEGRATING BOND GRAPH AND GENETIC PROGRAMMING

In order to integrate a genetic programming approach with a bond graph, an embryo model is needed. The embryo is an initial model which must include input, output and basic elements of the desired system. It has modifiable sites on the elements or junctions. These modifiable sites can be evolved by using pre-defined functions such as Add-Element, Insert-Junction, Add-Num and End. These functions used for creating a GP tree based on the bond graph method. An example of a random GP tree is shown in Fig. 1. By applying this tree to modifiable sites on the embryo model, an evolved system obtained and fitness value calculated.

3. RESULTS AND DISCUSSION

In the mechanical domain, a Mass, Spring and Damper (MSD) system is considered for a given transfer function [6]. The embryo model used for the mentioned system is shown in Fig. 2. It has a modifiable site on 0-Junction which is shown with a dashed-line circle. Input force to the system is applied to mass m_1 and output considered as the vertical velocity of mass m_2.

Transfer function of desired mass, spring, and damper system is [6],

$$H(s) = \frac{4s + 40}{s^3 + 40s^2 + 400s} \quad (1)$$

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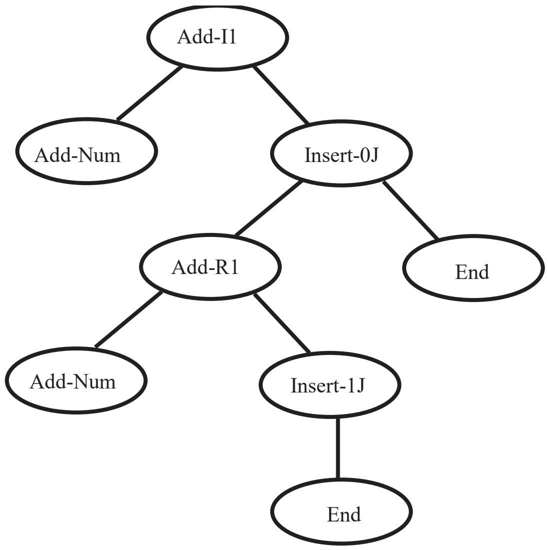

Fig. 1. An example of a GP tree based on bond graph

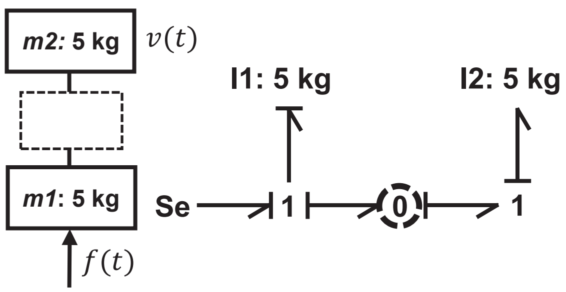

Fig. 2. Embryo model for a MSD system

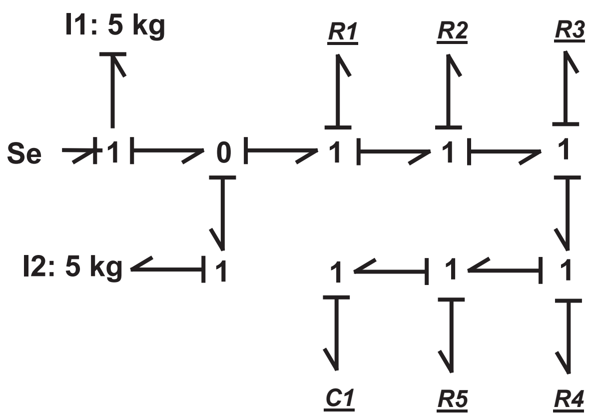

Fig. 3. The evolved MSD system in single-objective approach

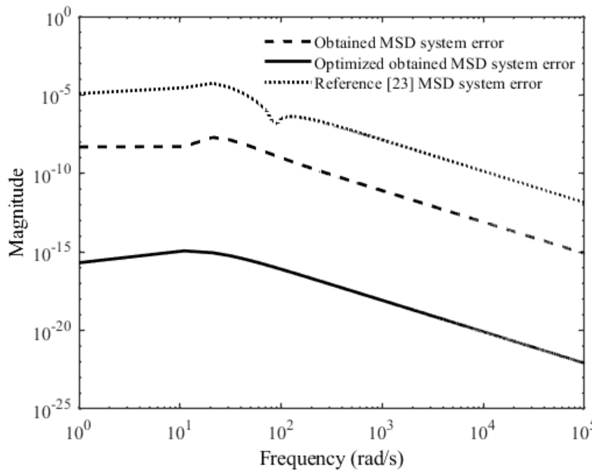

Fig. 4. Comparison of absolute error for the present study MSC system and reference model [6] in one-objective approach

Table 1. Objective functions of chosen design points in multi-objective topology design approach

Design point	Absolute error	Depth of the tree
A	7.4566×10^{-8}	7
B	7.4566×10^{-8}	5
C	0.003894	3

Two approaches for calculating fitness has been considered in this article. First, in a single objective approach, the absolute error between the system model obtained by the present approach and desired transfer function calculated and the best candidates extracted. The bond graph model of the evolved MSC system is shown in Fig. 3. It can be seen that five *R* elements and a *C* element added to the embryo model. Since the presented method focused on designing new system topologies, newly added elements might not be optimized in terms of value. So, a second step optimization on new elements must be done by using a genetic algorithm. After optimizing the best optimum design point, it can be seen that absolute error decreases significantly which is shown in Fig. 4. In this graph, a comparison between the best individual, optimized best individual and reference model is shown.

In the second part, a two-objective approach of the proposed method is investigated. It should be noted that if the depth of the tree increases, the system becomes more complex. Therefore, it is recommended to decrease the number of depths to obtain a system with lower complexity. For this reason, in this section in addition to absolute error, the depth of the tree is also considered as the objective function. By considering the mentioned objective functions and embryo model, a Pareto front of non-dominate design points for the MSC system obtained. Three optimal design points *A*, *B* and *C* are chosen from the best front and its objective function values are given in Table 1. The GP tree of design point B is shown in Fig. 5.

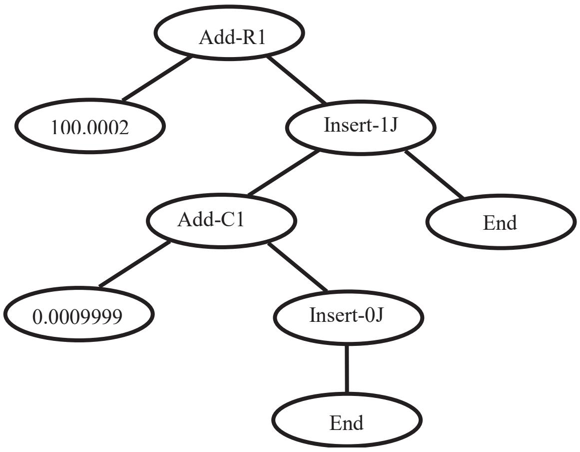

Fig. 5. GP tree of design point *B*

4. CONCLUSIONS

This paper presented two approaches to the design evolution of a system by using integrating genetic programming and bond graph modeling methods. A mass, spring and damper system with a given transfer function considered as the desired system. In the first approach, after obtaining the best topology, values of newly added elements taken into a second step optimization and absolute error of frequency response decreased significantly. In the second approach, a multi-objective topology design presented by choosing the depth of the tree and absolute error as objective functions. The results of this approach also were obtained and the simplest possible system was achieved. The results of both approaches showed a lower absolute error in comparison to the reference model [6].

5. REFERENCES

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