Bond-Graphs + Genetic Programming = Automated Synthesis of Mechatronic or Multi Domain Dynamic Systems

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Bond-Graph Modeling of Analogous Physical Systems

Intuitive Bond-Graph Model of the Analogous Mechanical and Electrical Systems

Schematic Representation of a Spring-Mass-Damper System
- Mass M and inductor L replaced by inertia I.
- One junction is representation of physical constraints in both systems.

Schematic Representation of a Resistor-Inductor-Capacitor System
- Spring stiffness K and capacitor C replaced by compliance C.
- Force F(t) and voltage source V replaced by source of effort SE.
- Damper R and resistor R replaced by resistance R.

Causality determines relationship between cause and effect variables.
Methodology for Combining BGs with GP
Evolving Bond-Graph Models

- Employing the outlined methodology a simulated experiment has been devised to combine Bond-Graphs with genetic programming for automated synthesis/design of a simple physical system.

- The evolved Bond-Graph model of the physical system and numerical values of all evolved parameters along with target performance are included in next slide.
Results of Simulated Experiment

The Final Simplified Bond-Graph Model

Summary of the Results

<table>
<thead>
<tr>
<th>Target Eigen Values</th>
<th>Solution Eigen Values</th>
<th>Average Distance Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1±2j</td>
<td>-0.78±1.063j</td>
<td>0.961</td>
</tr>
</tbody>
</table>

Evolved Structure on Write Head

| R Elements | 1 |
| C Elements | 1 |
| I Elements | 1 |
| Junctions  | 1 |
| Bonds      | 4 |

Bond-Graph Element Values

| R Element | 0.922 |
| C Element | 0.42  |
| I Element | 0.35  |
Using the final simplified evolved Bond-Graph model of the synthesized system physical design realization of a simple rotary mechanical system has been carried out appearing in next slide.

A complete dynamic analysis has been performed to cover the stability and controllability aspects of this synthesized physical system.
Synthesized Rotary Mechanical System

- DC Motor
- Coupling Shaft
- Rotary Inertia
- Bearings
- Friction Effects at Contact Surface

Power Source

Friction Effects at Contact Surface:
- $R_1 = 2.5 \times 10^2 \text{Nms/rad}$
- $R_2 = 5 \times 10^2 \text{Nms/rad}$
- $R_3 = 9.22 \times 10^{-1} \text{Nms/rad}$

Rotary Inertia:
- $I_1 = 3.5 \times 10^{-1} \text{Kgm}^2$
- $C_1 = 4.2 \times 10^{-1} \text{Nm/rad}$
Conclusion

- The novel methodology followed for combining Bond-Graphs with genetic programming offers a powerful tool for automated design/synthesis of multi-energy domain dynamic or mechatronic systems.

- The dynamic analysis (of the system in previous slide) reveals that a stable, controllable and human compatible physical system can be evolved by using the open ended design/synthesis paradigm offered by the outlined methodology.
Thank you for your attention.