Model order Reduction of Fractional-Order Systems: A Brief Overview of the Existing Techniques and Future Recommendations

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Researchers from a variety of engineering fields are very eager to investigate fractional-order (FO) systems, as their mathematical models have proved to be more effective in depicting various physical phenomena such as electrochemical processes, long-distance lines, dielectric polarization, viscoelastic materials, coloured noise and even chaos.

FO systems are fundamentally the approximations of the integer-order (IO) systems. The system dynamics of the FO systems include the non-integer differential or integral operators. It should be noted that the FO model reflects more reliable properties as compared to its IO model. However, the FO system is having infinite dimension. Thus, these infinite-order systems are approximated by finite integer-order rational models for the purpose of investigation, simulation and controller design.

In system theory, model order reduction (MOR) is a method of reducing the complex large-scale structure to a much smaller number of variables. It is an important functional challenge as it simplifies the understanding of the system dynamics, reduces the computational burden of simulation and improves the design of controllers. MOR is an age-old practice in integer-order systems, but a limited amount of research has been done on fractional-order models.

Mostly three types of FO systems are reported in the literature. They are respectively coined as commensurate, non-commensurate and fractional-order systems with non-rational powers. Commensurate type FO systems are those in which the non-integer powers of integrators and differentiators are multiple of real number and therefore such class of system can easily be transformed into IO system using simple assumptions. Non-commensurate FO systems involve non-integer terms which are not necessarily multiples of real numbers. Even FO systems with non-integer terms in the form of non-rational numbers also exist. Hence their analyses are not easy.

As per literature, the FO systems whether commensurate or non-commensurate are usually reduced by conventional techniques, direct truncation, singular perturbation methods, Padé-approximation, partial realization, shifted Padé-approximation, and rational interpolation methods to name only a few. While one wing of researchers used the state space form whereas others operated applied the transfer function approach. Another approach constitutes H_∞ norm-based technique to estimate the model parameters. Even Krylov-based method and Arnoldi-based technique also exist for reduction of FO systems. Oustaloup approximation technique is also a popular technique to convert this type of non-integer systems into an integer one. Some reduction techniques for multi-input multi-output (MIMO) systems, discrete-time and discrete-delta systems in the context of FO systems were also proposed. Moreover, mixed methods involving a soft computing technique were also formulated. The use of metaheuristic algorithms like Differential Evolution (DE) and a blend of Big-Bang Big-Crunch (BB-BC) and Particle Swarm Optimization (PSO) were also reported. Thus, from the literature it can be inferred that most of the classical reduction techniques employed for IO linear time-invariant systems have been applied for FO systems. Further, the use of soft computing techniques has not been explored so much. Only a single work in the unified delta domain is stated. This creates an opportunity for the researchers and scientists to explore new methodologies for the reduction of fractional-order systems.

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