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混合变量系统基于MCMC的自适应重要抽样法

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Adaptive Importance Sampling of Hybrid Variable Systems Based on MCMC

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摘要 系统关键故障的发生,会导致系统处于各种离散性能降级状态.针对传统的基于马尔可夫链蒙特卡罗(Markov chain Monte Carlo,MCMC)的自适应重要抽样法只适用于连续变量系统的不足,提出考虑混合变量的基于MCMC的自适应重要抽样法,以支持系统性能可靠性的高效仿真.该方法首先将由关键故障产生的不同失效域组成失效空间,并通过初始样本点在失效空间中随机游走构造马尔可夫链模拟样本;然后综合考虑连续变量与离散变量,利用核密度估计构建混合核抽样密度函数;再根据该密度函数进行重要抽样仿真并计算系统的性能可靠性;最后对该方法的仿真效率进行理论分析.通过电液舵机(Electro-Hydrostatic Actuator,EHA)案例对方法的正确性和仿真效率进行验证.

关键词: 失效空间 马尔可夫链蒙特卡罗 核密度估计 重要抽样 混合变量系统 性能可靠度

Abstract: The occurrence of key failures in a system may cause the system to degrade into different discrete states of performance. The classical importance sampling method based on Markov chain Monte Carlo (MCMC) can only be applied to a continuous variable system and cannot resolve the problem of mixed systems including discrete variables. Therefore, an improved adaptive importance sampling method based on MCMC is proposed to support the efficient simulation of system performance reliability. First, a failure space is constructed by combining different failure domains, and Markov simulation samples are achieved by the initial sample wandering in the failure space. Second, with a comprehensive consideration of continuous and discrete variables, a hybrid sampling density function is obtained through kernel density evaluation. Then, importance sampling simulation is operated according to the last hybrid sampling density function and the performance reliability is computed. Finally, the simulation efficiency is analyzed in theory. The validity and high efficiency of the proposed method are demonstrated by the case of an electro-hydrostatic actuator (EHA) system.

Keywords: failure space Markov chain Monte Carlo kernel density estimation importance sampling hybrid variable system performance reliability

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