Title	コンピュータグラフィックスにおける媒体中の剛体運動シミュレーション
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Abstract

This dissertation proposes a new topic, immersed rigid body dynamics, into the real-time computer graphics community. It is clearly different from the other traditional topics in computer graphics that the research aim of immersed rigid body dynamics is to simulate the motion of rigid body fully immersed or submerged inside real flows, and strongly coupled with the surrounding flows. This dissertation presents a family of algorithms for real-time simulations of immersed rigid body dynamics in computer animation. These algorithms are built on data-driven simulation methods to simulate the rigid body dynamics with the flow effects in computer environment. These approaches make it feasible to achieve realistic simulation results in low computation cost. In addition, a promising prior reduced model of dynamical systems is introduced for the parameter identification into computer animation.

The first contribution is a graph-based framework for synthesizing the motions of immersed rigid body, which are commonly lightweight. This framework is a first try to combine the motion graph technique in character animation field with the physics-based simulations. The typical motion patterns of immersed rigid-body dynamics are extracted in a phase diagram and verified from thousands of physical experiments to construct a precomputed trajectory database and the transition probabilities in Markov-chain model of the motion graph. Finally, an improved noise-based algorithm is proposed for integrating the wind field with the simulation results.

The second contribution is a stochastic model of immersed rigid body dynamics. This model first utilizes energy transport model of the surrounding turbulent flow to approximate the energy distributions due to the rigid body motions. Then, the proposed turbulent model is successfully introduced into a generalized Kirchhoff representation of the rigid body dynamics with Langevin model in a stochastic Wiener process. The proposed model adopts a new approach combining the precomputed simulation data of turbulent energy and the runtime simulations of rigid body solvers.

The third contribution focuses on a pattern-driven framework for immersed rigid body dynamics. This simulation framework first classifies the influences of parameter spaces of viscous force coefficients in a data training process, and then proposes a curvature-based motion planning method to represent the unsteady dynamics due to the vortex shedding. The proposed methods learns the knowledge of parameter subspaces of the rigid body dynamics from numerical experiments in a new dynamical model, which clarifies the viscous forces from the surrounding flow into three components and reveals the relationships among the force coefficients, the Reynolds number, and angle of attack of the body. In addition, the proposed framework combines the motion graph technique from the graph-based framework and the energy optimization in motion synthesis from the stochastic model.

Finally, a novel reduced model of dynamical systems is constructed, which can accelerate the parameter estimation of physical parameters in a dynamical model with low computation cost. In contrast to the conventional reduced order models, the proposed model is a prior meta-model of dynamical systems based on the separated representation in large domains including initial conditions, boundary conditions, and physical parameters. The proposed model does not depend on the preprocessed snapshots of the solutions from dynamics solvers. This model is successfully applied to the weakly coupled and nonlinear problems. The improvement of the proposed reduced model in strongly nonlinear problem, such as immersed rigid body dynamics, is worth being anticipated.

Keywords:
Data-driven Simulation, Motion Pattern, Reduced Model, Flow Effects, Computer Graphics