A robust rigid body interaction model for friction-induced sound synthesis


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A ROBUST RIGID BODY INTERACTION MODEL FOR FRICTION-INDUCED SOUND SYNTHESIS

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Acoustic synthesis for frictional sound modelling is a challenging task because of nonlinear coupling in friction phenomenon, in achieving a coherent perceptual audio-visual consistency, especially for games and virtual environments. In this paper we studied and presented an advanced friction model that simultaneously synthesizes both the high-rate sounds and low-rate video phenomenon based on lumped modal description of resonating bodies. An efficient technique and algorithmic chain are developed to demonstrate the low-cost and real time framework for the proposed discretized nonlinear dynamical frictional model using modal analysis. The developed methodology incorporates all interactions that occur in strong-contact conditions having nonlinearity and are dynamically imposed force dependent. Audio-visual animations are developed in order to implement the proposed methodology that showed a perceptual consistency in both audio and video and in reproducing sound of several materials in everyday frictional phenomenon.

1. Introduction

Recently, the friction modelling is an interesting research area in the field of computer graphics, haptics interactions and virtual sound modelling. The main objective is to develop models of virtual sound rendering for sliding contacts of rigid bodies [1], especially in interactive games and virtual reality environments. Frictional interactions produce strong nonlinear coupling phenomena that possesses diverse acoustic behaviours. A few resonating modes can produce various rich sound effect during the contact interactions of graphical objects. To achieve a coherent and perceptually rich audio-visual cues consistency for the rigid bodies' interaction, researchers have developed various friction models for rendering virtual sound. These models for audio-visual synchronization have certain deficiencies to deliver such a coherence, particularly for interactive processes.

In this paper we propose and investigate a model for friction sound synthesis to integrate audio-visual cues that is based on physical modelling. First, a physically-based friction model is designed and developed, proposed in [2], as the coupling mechanism among different resonators in contact. A numerical model is designed to demonstrate the effectiveness of the model during real time on low computational cost. Secondly, we implemented the model to simulate different daily friction phenomena for audio-visual interactive animations. The friction phenomena happen in contact conditions and are dependent on the forces.

2. Related Work

Foley art is commonly used to produce different sound effects onto game sounds and virtual reality applications including automatic soundtrack production during computer animations [3]. Though the sounds produced by Foley automatic are quit realistic, yet they are not for real-time and interactive phenomenon [4]. In physically-based sound synthesis methods the modelling of the interacting sound producing objects are proposed with different approaches. Van den Doel et al. in [5] proposed modal synthesis for accurately synthesizing the virtual sounds for rigid bodies. In his study, the modal resonators' parameters are derived from objects' geometry and their physical descriptions. O'Brien et. al. in [6] proposed the used of rigid body simulators to synthesize real-time sounds in interactive applications, where, the finite element modelling (FEM) is applied on each object for computing the frequencies of their potential modes. These models use contact forces to figure out the modal model, assuming that the sound producing phenomena are linear and generally meant for no-interactive applications. Details are provided in [2] about sliding and scraping object's sounds.

3. Methodology

Steady velocity models are commonly used to describe the interaction between bow and string for physical modelling of bowed string instruments, where, the friction force f_{fr} is assumed to be a function of the relative velocity between bow and string at a given fixed bow pressure. The following equation describes the friction force of steady velocity

$$f_{fr}(v) = \mathrm{sgn}(v)[f_c + (f_s - f_c)]e^{-(v/v_s)^2}. \tag{1}$$

Here, f_c is the Coulomb force and f_s is the stiction force whereas v_s is Stribeck velocity. The Coulomb force is less than the stiction force.

More advanced dynamic models are used to overcome the dependence of f_{fr} onto the velocity and are modelled using differential equations. These dynamic models are capable to consider pre-sliding behaviour for small displacements [7]. Dahl in [8] proposed a dynamic model that accounts only for pre-sliding displacement, ignoring the Stribeck effect, whereas, LuGre in [9] extended Dahl model to incorporate the Stribeck effect. However, this model has drift for random minor external forces that makes it physically inconsistent and it does not allow purely elastic regime, therefore, an elastoplastic models has been proposed in [2].

This model explains a continuous contact between two objects (resonators). In the formulation the resonators are considered as rigid (2D plan) with an infinite mass and an impactor or interactor (bow). We denoted the two objects with "b" for bow and "r", for resonator. These objects are subjected to interact through the elasto-plastic friction force. The mathematical formulation for the continuous-time are

$$m_{bi}\ddot{x}_{bi} + r_{bi}\dot{x}_{bi} + k_{bi}x_{bi} = f_{be} - f_{fr} \qquad (i = 1 \ldots Nb) \tag{2}$$

$$m_{rj}\ddot{x}_{rj} + r_{rj}\dot{x}_{rj} + k_{rj}x_{rj} = f_{re} - f_{fr} \qquad (i = 1 \ldots Nb) \tag{3}$$

$$v = \sum_{i=1}^{N_b} \dot{x}_{bi} - \sum_{j=1}^{N_r} \dot{x}_{rj} \qquad (reltive\ velocity) \tag{4}$$

$$y \triangleq \dot{z} = f_{NL}(v,z) = v\left[1 - \alpha(z,v)\frac{z}{z_{SS}(v)}\right] \tag{5}$$

$$f_{fr} = \sigma_0 z + \sigma_1 \dot{z} + \sigma_2 v \qquad (friction\ force) \tag{6}$$

$$z_{SS}(v) = \frac{sgn(v)}{\sigma_0}\left[f_c + (fs - fc)e^{-(\frac{v}{v_s})^2}\right] \tag{7}$$

Here, the all x are model displacements and z is the mean bristle displacement. The terms f_{be}, f_{re} are external forces and integers N_b and N_r are the number of modes for the bow and the resonator, respectively. Expressions for a and z_{ss} are described below in Eq. 7 and Eq. 8 and taken from [9].

Here, f_c is the Coulomb force, fs is the stiction force and v_s is the Stribeck velocity.

$$\alpha(v,z) = \begin{cases} 0 & |z| < z_{ba} & If\ sgn(v) = sgn(z) \\ \alpha_m(v,z) & z_{ba} < |z| < z_{ss}(v) & If\ sgn(v) = sgn(z) \\ 1 & |z| < z_{ss}(v) & If\ sgn(v) = sgn(z) \\ 0 & & If\ sgn(v) \neq sgn(z) \end{cases} \tag{8}$$

Here, z_{ba} is the breakaway displacement, the function $\alpha_m(v, z)$ describes the transition between elastic and plastic behaviour and is parametrized as discussed in [9].

$$\alpha_m(v,z) = \frac{1}{2}\left[1 + \sin\left(\pi \frac{z - \frac{1}{2}(z_{ss}(v) + z_{ba})}{z_{ss}(v) - z_{ba}}\right)\right] \tag{9}$$

4. IMPLEMENTATION

The friction model illustrated in Section 3 has been implemented in Unity 3D environment. We developed algorithm for resonators, where the methods of modal resonators are formulated. Secondly, interactors are developed for friction interaction: a function that calculates the forces applied to the resonators as described in previous section. Finally, sound synthesis model is designed where the resonators are linked by a friction interactor. The whole schematic is represented in Fig.1 as flow process.

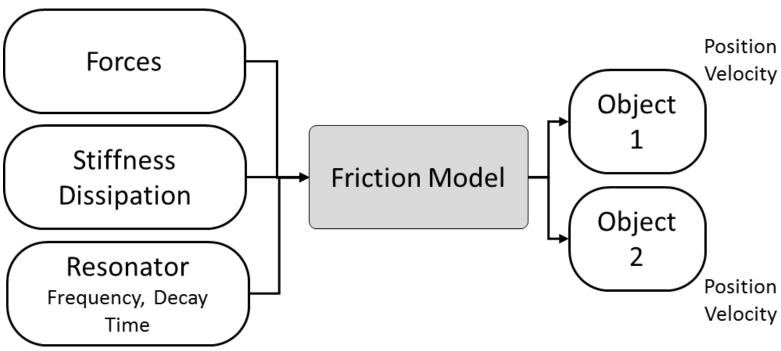

Figure 1: Implementation of friction model.

5. AUDIO-VISUAL SIMULATIONS

The model illustrated in previous sections has been applied to different scenarios where synthesis of frictional sound is conducted. To validate the model and the algorithms in graphical environment, simple animations are produced for three cases, where, different material objects are sliding.

A scenario is developed where three different boxes of different materials are sliding on three inclined surfaces. The sounds produced by sliding phenomena for each case are shown in Fig. 2. We have selected three objects of three different materials; wood, steel and glass. These objects are square in shape and are subjected to slide over slabs of same material respectively.

Figure 2: Scenario for simulation and corresponding sounds.

6. CONCLUSION

In this paper, we have presented an approach synthesizes audio for a sliding contact among rubbed surfaces. The approach incorporates modal synthesis with nonlinear friction model that simulates different frictional interactions for sliding. Unity 3D platform was used for audio-visual simulations where the physical rendering from the physics engine is exploited for animation. The results propose that for the strong contact, more refined approach for excitation is needed that is achieved by modelling of nonlinear friction model. Finally, the sounds are generated for all scenarios and a complete coherence is achieved between audio and video modalities.

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