Real-Time Physical Model of a Cymbal Using the Full von Kármán Plate Equations

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ABSTRACT

Metallic idiophones like cymbals or gongs have been shown to exhibit nonlinear acoustic effects such as mode coupling, pitch glides or transitions from deterministic to chaotic regimes for a wide range of excitation patterns. Capturing these effects in a physical model is essential when aiming at realistic simulation and synthesis results for research or musical applications. The von Kármán (VK) plate equations have been successfully applied to model nonlinear effects typically found in cymbals, gongs or stiff membranes. But, capturing these complexities in a structural vibration model comes with the drawback of higher computational cost when compared to more simple plate theories as the Kirchhoff or Berger plate models. Indeed, when written in full form, the VK plate equation is composed of a system of three coupled differential equations, one for the transverse motion and two for the in-plane (longitudinal) motion of the modeled plate. This leads to the predicament that the VK equations are not easily implementable in real-time on standard hardware for reasonably sized simulation domains. Utilising specialised hardware platforms such as general purpose graphics processing units (GPGPUs) or field programmable gate array (FPGA) hardware, has been shown to be a viable alternative for accelerating physical models of musical instruments enabling real-time simulation and auralisation of complex large scale geometries. In this work, a real-time version of the full VK equation system implemented on FPGA hardware is presented. The model is computed on a development board consisting of two FPGA chips that can be parametrized and controlled from a personal computer. The VK model is discretized using finite difference approximations for the spatial domain and is iterated in time using a locally symplectic iteration scheme leading to a fully explicit formulation of the problem. The excitation is modeled as a simplified stick-cymbal interaction that can be parametrized from a personal computer. Different stroke patterns are used to excite the model and resulting vibrations are compared to measurements taken on a real cymbal showing the variability of the simulated sound and giving realistic physical bounds for the proposed implementation.