Nonlinear dynamics in musical acoustics : characteristics, models and sound synthesis

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Abstract Musical instruments are all concerned with a nonlinear characteristics, making the sound interesting to the ear and the problems challenging for the physician. In this presentation, we will give an overview of the nonlinear phenomena appearing in a number of musical instruments, without the aim of exhaustivity. The sound of friction, the acoustic nonlinearity occuring in brass instruments and giving rise to their particular rich tone will be surveyed, and a particular emphasis will be given to contact and geometric nonlinearity.

The physics of musical instruments always present a nonlinear characteristics, making the sound interesting and pleasant to the ear with the generation of a peculiar timbre [1–3]. Consequently the understanding and modeling has to cope with various and complex nonlinear phenomena that will be surveyed in this talk. When one thinks of the particular sound of a brass instrument, the high-frequency content generated by contact dynamics in indian stringed instruments such as tanpoura and sitar, or the wave turbulence at hand in the nonlinear dynamics of gongs and cymbals, one has to face a number of smooth and non smooth nonlinearities that are key in the sound production and cannot be neglected. Moreover, the sensitivity of the human perception makes the problems difficult to solve for sound synthesis as any small amount of numerical dispersion, or any mismodeling in the loss mechanisms and resulting decay rates, are immediately recognized by the ear as non physical, resulting in poor and unrealistic sound synthesis.

The talk will survey the main nonlinear characteristics in musical instruments. Without the aim of exhaustivity, the key components creating the typical sound of bow instruments, brass instruments, gongs and cymbals, and the problems of collisions, will be overviewed. More particularly:

- the sound of friction is key to understand the bowed string dynamics. The Helmholtz motion and the particular stick/slip dynamics will be reviewed, as well as the effect of rosin. The playability of the bowed string, which gives an idea of the boundary limits where Helmholtz motion occurs as function of the dynamical input parameters, will be explained [4–6].

- the brassy sound is generated by nonlinear acoustics propagation in tubes. The effect will be briefly explained [7]. For wind instruments, another interesting nonlinearity also occurs in reed instruments, where a nonlinear characteristics between pressure and air flow velocity is needed to ensure the birth of oscillations through a Hopf bifurcation [8].

- Collisions are present in a number of musical instruments. A special emphasis will be given to contact dynamics occuring in stringed instruments and used in order to create a specific tone, such as the one of indian instruments (sitar, tanpura) [9–12].

- The sound of turbulence is typical of percussion instruments such as gongs and cymbals. These instruments are characterized by a a broadband Fourier spectrum instead of having a definite pitch. Geometric nonlinearity occuring due to large-amplitude vibration of those thin structures, generates a wave turbulent regime with an energy flux from the low to the high frequencies, resulting in the particular sound of these instruments [13, 14].

Models used for sound synthesis of these instruments will then be exemplified and a particular emphasis on contact dynamics and thin plates dynamics including geometric nonlinearity will be shown with dedicated sound synthesis examples.

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