THE SOUND OF A PLECTRUM, FINGER OR FINGERNAIL PLUCKED STRING

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1. SUMMARY

This project involves various methods to generate the attack sounds corresponding to finger, fingernail or pick plucked string. A review on existing techniques is given. A few particular approaches of attack-decay envelope, excitation wave-table and bowed-string model are implemented which show the ability to give finger-like plucking. However, the sound of pick-plucking is not so successful, possibly due to the lack of more important part of the vibration of the pick itself, though normal plucked string with some damping can already give pick-plucking sound. Different initial displacement conditions are also shown to contribute virtually nothing to the desired initial plucking sound.

2. INTRODUCTION

The physical model of a plucked string has been well-studied and even its simplest form of a linear model can already give a computer simulated sound which is considerably close to the real instrument. However, to have a sound that resembles more closely to a real string instrument and better control in synthesis, we need to model in details of what is actually going on in a sound production of such instruments at the expense of more computation and memory required. Regarding the string excitation, a lowpass-filtered noise has been used successfully as an excitation. The result is a sound that is almost indistinguishable from the real one despite being rather non-physical. Its success might be explained (in my view) in reference to a guitar body impulse response which has been stripped off its most slowly decaying modes, leaving only noise-like impulse response as an excitation, which also gives similar result.

To have a greater control on plucking, other models might be worth looking at and implementing. Furthermore, it should be desirable to have a choice of synthesizing a guitar sound, for example, being plucked by a finger, a fingernail or different kinds of plectrum (some rockers even use their teeth!). Despite being only a small part of a plucked string sound, to many musicians, different ways of plucking do cause different sensation. Given this motivation, this report attempts to find out more on how we can best generate a sound of guitar being plucked by finger or a pick from past research and experimentation. It will also attempt to find out whether the perception of pick-plucking and finger-plucking might actually only depend, or largely depend on just the initial condition of the string, and not the sound created by the friction of the excitation agent and the string itself. A search into past work in this area of plucking string model did not yield many results (with one in Japanese [2]). Most of the guitar sound synthesis programs implement different plucking styles using pre-recorded sample tables [4] [3] with, at most, an additional pluck filter to adjust for minor differences. However, general friction models which have been applied mostly to bowed string can be adapted for our purpose. All experimented results carried out in this report are posted on the web at *http://www.stanford.edu/ pj97/421/421-proj.html*.

3. PRODUCTION MODELS

3.1. Shape of the Initial Displacement

One might ask if the sound of plucking by different material is just a result of different shape of the string displacement before release. For example, plucking by a pick should give a cornered string displacement resulting in a sharp sound while a finger will give a more curvy one and hence a more rounded sound.

The hypothesis was tested using a displacement wave on two delay lines, given different displacement initializations. The result is, there is hardly any difference by listening. Even if there was, it did not give the impression of pick-plucking when the displacement started from a triangular shape (whose apex is slightly rounded off to avoid aliasing). Similarly for a smoother curve string which might have corresponded to a rounder object like finger. This suggests that what we hear which discriminates one plectrum from another comes from the actual sound of the plectrum, or finger, interacting with the string. Also, even if the initial shape gives different sensation, its implementation is computationally intensive for synthesis due to the need of many displacement calculation points.

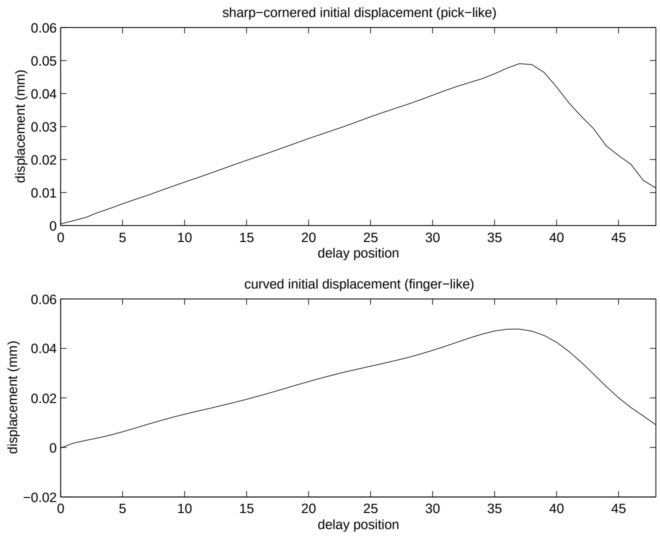

Fig. 1. (Top) Sharp-cornered initial displacement for pick-like simulation. (Bottom) Low curvature initial displacement for finger-like simulation.

3.2. Non-physical Implementation

A commercial product Six-String by Cremeware©offers control on plucking via attack-decay envelope in which the excitation comprises basic energy and noise energy [8]. The basic energy is related to the envelope amplitude while the noise energy is related to the amount of excitation. The ”pro” control version also allows for filtering of the noise and time modulation by velocity parameters. This is basically the Karplus-Strong excitation by filtered noise which is shaped in time-domain by the attack-decay envelope.

In this experiment, a velocity wave is implemented using a commuted synthesis. The guitar body impulse response is used as an excitation which is then passed through the excitation filter, implementing different initial plucking condition. The filter impulse response is an asymmetric hanning window whose shape is governed by the attack and decay rate and amplitude input, imposed on the filtered noise samples with a controllable energy (related physically to plucking velocity). The noise can also be bandpass-filtered to give a desired characteristic. For example, lowpass filtered noise gives softer (rounder) sound, closer to nylon string, while high-frequency bandpass filtered noise gives a sound inclining toward a metal string end.

From experiments, slow attack (long rise time) gives the friction-like sound at the attack of the note, quite like a dry finger plucking. Faster attack gives a crisper sound but it can hardly give the attack sound of a pick-plucked string. This suggests that it is not the friction, but maybe the clicking which is not from the string but the pick itself, that matters in the case of a pick-plucking.

3.3. Bowed-String Model for Initial Friction

One can imagine a one-dimensional model where we pluck the string by our finger by dragging the finger over the string, taking the string with it while the tension in the string is less than the friction. The friction depends on the finger pressure and its velocity. When the tension exceeds the static friction, slip occurs, resulting in the string movement under the finger with reduced but still non-linear friction. Though it is a simplified model considering we actually displace the string by pulling it until it slips from the grip, it can give the sound of friction when the setting is right. We also have the bowed string model which, by suitable adaptation to finger or a pick, might give a realistic impression.

The existing STK bow table and an upgraded version which also allows velocity control are both used in the experiments [7]. Physical measurements are needed to chart a proper non-linear relationship of velocity, pressure and the resulting friction. In this project, however, the parameters in the existing tables from the bowed string model are only adjusted heuristically. Again, the resulting friction-like sound can be made to sound as if it was from using a finger, though it sounds too dry for a finger which is to be expected from a bowed string. The last wave state from the friction part is fed as input to the usual pluck string model to ensure state continuity. However, the problem of sound continuity and fusing of bowed string sound and the following free vibration still arises. It can be mitigated by the use of suitable amplitude decay and rise so that friction is less pronounced and fused better with the string vibration. Here, an exponential decay is used.

Although a friction sound can be produced in this way, the sound of a pick-plucking cannot be achieved. It can only give at most, a pluck string with no significant attack. It sounds more closely to a finger-plucked string with not too much dryness in the friction.

3.4. Initial Excitation Wave-table

This is probably one of the most widely used technique in generating a realistic and different attack sound [5]. A sound of a string played by a finger or a pluck, or in fact, by any other material, on a nylon or metal string is recorded and stored in a table. The string is highly-damped to remove the oscillatory part, leaving only the actual plucking sound. Some use inverse-filtering on the recorded plucked string to obtain the residual corresponding to the excitation and use this as an excitation in subsequent syntheses. It is reported to give more realistic sound when compared to noise-excitation algorithm, though with faster decay [4] due to its envelope and limitation in excitation energy.

3.5. Elasto-Plastic Friction Model

There exists a general model for friction between two surfaces. An elasto-plastic model of non-linear friction between two dry resonating surfaces is proposed along with the efficient numerical implementation in [1]. The model is based on forces acting on a large number of bristles on the surface each contributing a fraction toward the total friction. Each bristle is modeled as a linear spring being deflected when the surfaces slide over each other. If the deflection is large enough, the bristle will slip. The differential equations relate the friction to the relative velocity between the two objects, the averaged displacement and velocity of the bristle. It solves the problem of earlier (*LuGre*) model which exhibits drift for arbitrarily small external forces, in contradiction to reality. This is done by introducing a non-linear function which dictates the elastic behavior of the pre-sliding, when the bristle displacement is smaller than a breakaway value. Along with the state space model relating the dynamics of the two objects in contact, we have a set of equations which explain the whole system. The bilinear transform is used to convert the setting into discrete time. While earlier models usually have a fictitious delay inserted to avoid a delay free path, in this paper, the Newton-Raphson algorithm is used to solve the remaining recurrent equations with a delay-free path left as it is.

The model has been used to construct and control a bowed string. It predicts the same qualitative behavior (the hysteresis loop) as the plastic model by Smith and Woodhouse [6] of a bow string where the rosin is observed to deform at the bow contact point in relation to temperature. This model allows a variety of sounds of rubbed dry surfaces to be synthesized. However, parameter fine-tuning remains especially when one of the surfaces is moist like a finger. Because of time limitation and the level of difficulty of the algorithm, only the description is given here without implementation.

4. DISCUSSION AND CONCLUSION

From experiments with parameters adjusted closest to the desirable sound, the excitation wave-table approach gives a convincing sound and fast synthesis. Its drawback is the limitation in control and variety of possible excitation. The attack-decay envelope approach is fast but yet its control is not directly physical though may be good enough (excitation noise energy proportional to pluck velocity, rise time related to friction). The bowed string model can be applied successfully to generate a friction sound at the beginning with high flexibility in control on (finger) pressure and velocity. However, it requires more computation and fusing from friction-excited string to freely-vibrating string is problematic. A general elasto-plastic friction model would have offered more controls but then more parameters to tune and more computation to make.

For a pick-plucked string, it seems unlikely that friction model will help that much in generating a sound. A model of a vibrating bar having different geometry and stiffness with an interaction with a string is probably what is needed.

5. REFERENCES

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