ON THE EXTRACTION OF EXCITATION FROM A PLUCKED STRING SOUND IN TIME DOMAIN

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1. INTRODUCTION

Since the emergence of the concept of physical modeling synthesis, plucked strings have been one of the major applications. The sound quality of plucked-string physical models is often highly dependent on the excitation model, or the way that energy is input into the system. The first quasi-physical model of plucked strings was presented by Karplus and Strong (Karplus and Strong, 1983) and used a noise signal as a pluck excitation. A series of works (Välimäki *et al*., 1996, Erkut *et al.*, 2000) addressed the extraction of the pluck excitation using more advanced physical models, such as digital waveguides (DW) (Smith, 1992) and a single delay loop (SDL) model (Karjalinen *et al.*, 1998). In this paper, we propose a simple but physically intuitive method to extract the excitation signal from a plucked string signal in the time domain. By observing the behavior of the traveling wave components in the given plucked string sound signal and comparing that to a DW simulation, the pluck excitation is 'visually' identified and extracted simply by time windowing.

2. TIME DOMAIN PROFILE OF A PLUCKED STRING SOUND

2.1 Plucked string signal

In order to observe the motion of a string when plucked, a string of an electric guitar is plucked and the output signal from an electromagnetic pickup is recorded using a high impedance port of an audio interface. As both terminations of an electric guitar string are almost ideally rigid, especially compared to an acoustic guitar, a signal captured by the electromagnetic pickup mounted on the electric guitar is preferred to a signal of acoustic guitar string recorded by a microphone. Figure 1 shows an example of the recorded signal, $y(n)$. To obtain $y(n)$, the middle (approximately 32.4cm away from the bridge, at the 12th fret) of the lowest E string of length 64.8cm is plucked by a plectrum and the front pickup (the one closest to the nut) is chosen to capture the signal. The distance between the bridge and the front pickup is 16cm and the sampling frequency f_s is 44100 Hz. The fundamental frequency f_0 of $y(n)$ is 83Hz, estimated simply by referring to the spectrum and the autocorrelation of $y(n)$.

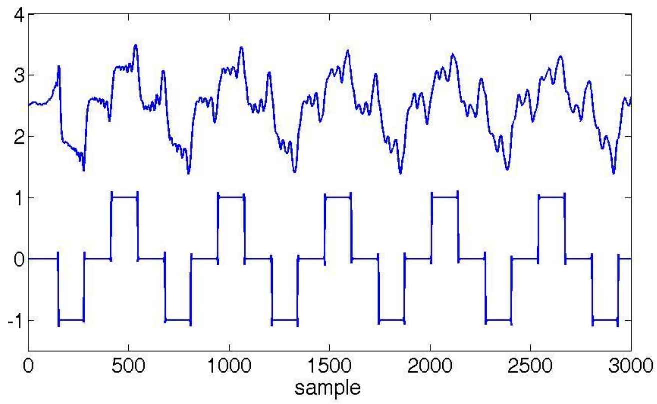

Figure 1. Top : A plucked string sound signal of an electric guitar $y(n)$; Bottom : DW simulation of the plucked string sound, v_{Lp}.

2.2 DW simulation of a plucked string

A DW simulation of $y(n)$ is carried out for comparison to the recorded $y(n)$. Figure 2 illustrates the DW model used for this simulation (Karjalinen *et al.*, 1998). The length of a delay line L is $f_s/2f_0$ = 265.6 samples. The pickup position L_P can be calculated by subtracting the number of delays representing the distance between the bridge and the pickup from L. Thus L_P becomes L-16× 266/64.8= 200.3210. Fifth-order Lagrange interpolation is employed to deal with fractional delays. For simplicity, $R_b(z)$ and $R_f(z)$ are assumed to be -1, only functioning as phase inverters. Acceleration wave variables are simulated in the DW system because an ideal pluck corresponds to an acceleration impulse. $I(z)$, the first-order integrator defined as $1/(1-z^{-1})$, accounts for the characteristic of an electromagnetic pickup which detects the velocity wave (actually, change in the magnetic flux). Thus, to obtain the impulse response of the model, $a(n)$, the input acceleration, is set to -1, assuming a downward pick direction. $a(n)$ is then equally split to $a_1(n)$ and $a_2(n)$ ($a(n) = 0.5a_1(n) + 0.5a_2(n)$, $a_1(n) = a_2(n)$) and fed into each delay line as shown in Figure 2. Then, $a_{Lp}(n)$ in Figure 2 is a sum of $a_{1,Lp}$(n) and $a_{2,Lp}$(n) that goes into the pickup.

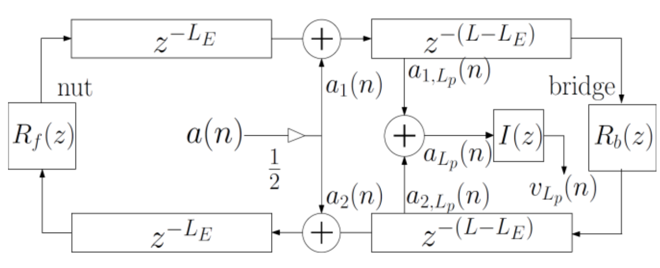

Figure 2. DW pluck string model

3. EXCITATION EXTRACTION IN TIME DOMAIN

In Figure 1, the impulse response of the DW model $v_{Lp}(n)$ and the recorded signal $y(n)$ are depicted together for comparison. We are able to note the similarity in the time evolution of the 'bump' patterns in both $y(n)$ and $v_{Lp}(n)$. The phases of bumps in $y(n)$ and $v_{Lp}(n)$ vary in the same manner. However, the signal we actually see in $y(n)$ is in the velocity dimension as the pickup functions as an integrator. Thus considering that the excitation we wish to extract from $y(n)$ is in the acceleration dimension, we need to differentiate $y(n)$ to $y'(n)$ for comparison to $a_{Lp}(n)$. Figure 3 shows $y'(n)$ and $a_{Lp}(n)$ together. The signal phase, or reflection, characteristics of $y'(n)$ and $a_{Lp}(n)$ vary in a similar manner over time. This suggests that the excitation signal actually travels on the string in the same way that the impulse does in the DW simulation. Therefore, by carefully taking a look at both signals, we notice that the portion under the arrow in $y'(n)$ in Figure 3 corresponds to the first impulse in $a_{Lp}(n)$. If we assume that the duration of the pluck excitation used to generate $y(n)$ is shorter than the time interval between the first impulse and the second impulse in $a_{Lp}(n)$, the indicated portion in $y'(n)$ that we refer to as $a_{exc}(n)$ hereafter, the initial plucking excitation is not distorted by reflected wave components during this time period. Therefore, we can simply extract $a_{exc}(n)$ by windowing it out from $y'(n)$ as shown in Figure 4.

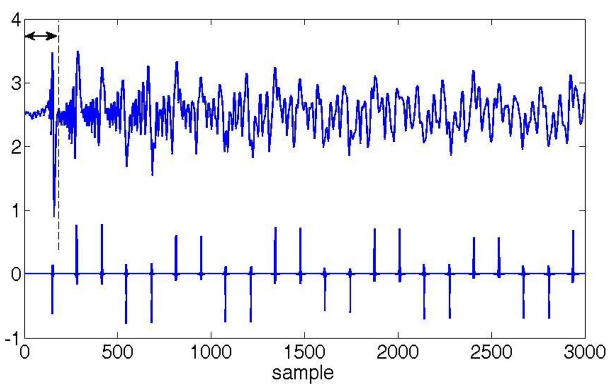

Figure 3. Top : $y'(n)$, the time derivative of $y(n)$. Bottom : $a_{Lp}(n)$

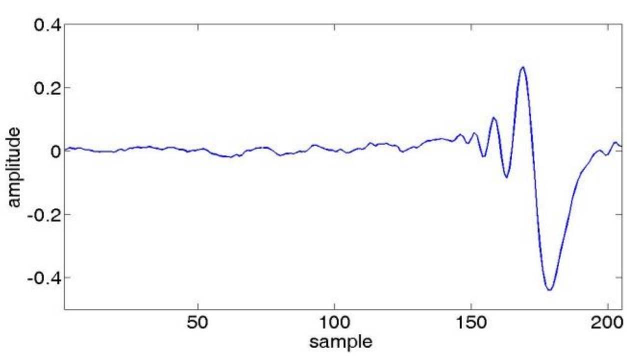

Figure 4. Enlarged portion indicated by the arrow in $y'(n)$ in Figure 3, defined as $a_{exc}(n)$.

Because the plucked string DW model is linear, this extracted excitation signal ($-a_{exc}(L_{exc}-n)$, where L_{exc} is the length of $a_{exc}(n)$) can be used as input to the synthesis model. To validate the proposed method, we synthesized a pluck sound by convolving $-a_{exc}(L_{exc}-n)$ with $v_{Lp}(n)$ and compared that to $y(n)$. As shown in Figure 5 where $v_{Lp}(n)$, $y(n)$ and the convolution of $y(n)$ and $-a_{exc}(L_{exc}-n)$ are depicted together, we can see that the synthesis result reproduces the signal pattern of $y(n)$ to a reasonable degree.

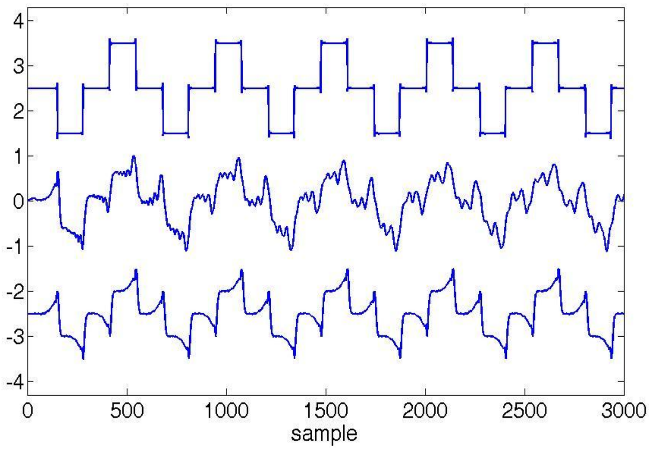

Figure 5. Top : $v_{Lp}(n)$, Middle : $y(n)$, Bottom : convolution of -$a_{exc}(L_{exc}$-$n)$ and $v_{Lp}(n)$

4. CONCLUSIONS

We have presented a novel method to extract the pluck excitation from a plucked string signal in the time domain. Our method is inspired by the observation of the way traveling wave components behave in the plucked string sound signal and by comparison with a DW simulation. The excitation extracted by the proposed method is compact and physically more meaningful, facilitating the use of the excitation for synthesis in conjunction with physical models such as DW. Future work will entail more systematic validation of the extracted excitation via inverse filtering approaches.

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