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Comparison of Impulse Response Methods for Guitar Modeling

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Abstract-Musical instruments and their modeling have captured a major part of research. Modeling involves methods of representation of these instruments. Impulse response modeling technique is one of them. Impulse response is considered to be the "fingerprint" of musical instrument. It gives us the very own characteristics of that instrument. It's been the key area where finding the impulse response of instruments and using them to produce notes powerfully audible is challenge! The paper is focused on discussion on various methods of finding impulse response by other researchers and then it talks about our experimentation with synthesis of Acoustic Guitar notes using Impulse Response approach in cepstral domain using adaptive windowing technique.

Keywords- *Modeling, Impulse Response, Acosutic Guitar, Cepstral Domain*

I. INTRODUCTION

Understanding the musical instruments mathematically is always a challenge. Fourier series analysis has been a very powerful tool to decompose a musical note and see its harmonics. Though it gives us the analysis and synthesis equations to toggle between time and frequency domain, we still have to compromise on the number of harmonics to be considered for synthesis. Researchers use Fourier Transforms for analyzing the musical note; still there has been a quest to find new tools to analyze and synthesize the music notes. Many researchers used the vocal tract response (VTR) approach to analyze music notes. Here we focus on discussion of Impulse Response approach towards the modeling of acoustic guitar notes by different researchers. Impulse response epitomizes the acoustic characteristics of musical instrument.

Fig 1 shows the structure of the acoustic guitar. We have recorded the musical notes of acoustic guitar model, FAW 802. It has six strings and twenty-one frets. We have recorded sound notes for all six strings along with its twenty frets. We considered two plucking styles, finger and plectrum, for the analysis. In total we analyzed 126 notes for single plucking style. Part II is focused on discussion of different Impulse Response approaches used by different researchers and their results. Part III discusses the methodology used by us and then Part IV gives the discussion of the results we got using Impulse Response Approach. Part V is the summary of our synthesis using cepstral domain adaptive window technique.

Figure 1. Structure of the box shaped Acoustic Guitar Body

II. DISCUSSION OF DIFFERENT IMPUSLE RESPONSE APPROACHES

In reference [3], Raymond V. Migneco and Youngmoo E. Kim, discussed the approach to model the plucked guitar tone using source filter model. The work aims to separate the source and the filter. The source is the guitar player's interacting style and filter is the electric guitar body. This implies the convolution of the player's articulation and the impulse response of electric guitar. We hereby call impulse response as body response. The approach is focused on modeling excitation signals by considering the player's interactions with string and the electric guitar body. Calibration methods for single-delay loop (SDL) model were implemented to find loop filter parameters. The scope of this work was limited to few sound notes from electric guitar and so the whole fret board was not covered.

Another work in this area is discussed in reference paper [4], by V.E. Howle, Lloyd N. Trefethen. Though this is not exactly focused on body response modeling, it has expressed the musical instruments in complex frequency plane as a set of points. This work has considered all the physical parameters of the guitar including the string losses, losses because of the string support at both ends and air losses. Surprisingly the complex domain representation clearly shows the effect of finger plucking and the plectrum plucking. Finger, if plucked gently in the middle, odd harmonics get really affected while even harmonics are less affected.

In reference [5], proposed by Friedrich Türckheim, Thorsten Smit, Carolin Hahne, and Robert Mores, the method adopted to measure the impulse response involves exciting the dampened strings at the bowing or plucking position by means of a thin copper wire which is pulled until it breaks. The experimental set-up was set up in anechoic chamber and then measurement was carried out by pulling the strings of violin by copper wire. The experimentation was carried out on violin; not on guitar. So the results for acoustic guitar were not available. This method demanded the anechoic chamber and provided no results for acoustic or electric guitar.

In reference [6], Matti Karjalainen and Julius Smith discussed the computational models for the guitar bodies. This work was focused on dividing the whole response of guitar body into least damped and most damped modes. Further the most damped modes were saved in the look up table and were used for synthesis. A tradeoff between memory and the computation was achieved by storing the most-damped modes effectively. In this work, it was suggested that properties of physical excitation may be incorporated. This indicated the use of the comb filter to obtain the virtual pick for the plucked string instruments.

In reference paper [9] by Friedrich v. Türckheim, Thorsten Smit and Robert Mores, the focus was to model the violin instrument. The computational efficiency was achieved with the help of FIR filters and the autoregressive parameter estimation. This was with consideration of player-instrument interaction. The methodology used for finding the impulse response was same as that of used in [4].

III. METHODOLOY

We adopted the cepstral domain approach to estimate the impulse response of acoustic guitar body as discussed in [2]. The various methods discussed above were analyzed with limited music notes. We collected 120 notes for single plucking style along with the 6 open strings for each plucking style. As discussed earlier, two plucking styles as finger and plectrum were recorded. The whole set was analyzed mathematically in [1]. After completing the mathematical analysis we began to work on impulse behavior of the acoustic guitar body.

A. *Block schematic of impulse method*

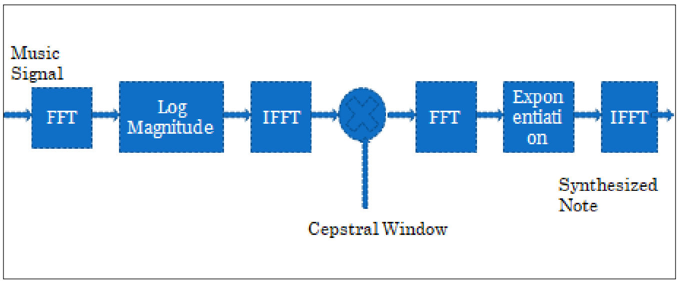

Figure 2. Block Schematic of Cepstral Domain Approach for Impulse Response Calculation

The music note for a single fret, e.g string 1 fret 1, is taken and its Fast Fourier Transform is calculated. We take logarithm of it and take the Inverse Fourier Transform to get the cepstrum of music note. Here we apply the window of variable samples to estimate the impulse response of acoustic guitar note. This approach is termed as “Adaptive Cepstral Domain Windowing, (ACDW)”. The estimation of the body response depends on the number of samples giving the best correlation coefficient. Correlation coefficient indicates the similarity between the original sound note and the synthesized music note.

This synthesis is carried out for the range of 50 samples to 300 samples. We observed that after 500 samples this correlation coefficient is drastically reduces, so we finalize the range of samples as mentioned above. After applying the cepstral domain window, we process the music note further and calculate its Fourier Transform again. Then the exponentiation of those samples is taken. Applying the Inverse FFT again, we enter in the time domain. This gives us the impulse response of the acoustic guitar note.

For estimation of the excitation signal, we omit these samples used for impulse response and the middle set of samples is further processed through FFT, Exponentiation and IFFT blocks. We finally convolve these two signals and get the synthesized music note.

IV. RESULTS

The correlation coefficients are calculated for the whole set of music notes for both the plucking styles and we get results with 0.95 as the maximum correlation coefficient. The finger plucked music notes give less correlation coefficient as compared with the plectrum plucked music notes. Further we carried out informal perceptual listening tests and did frequency calculations as well. The frequency values of synthesized notes are very close to that of the original notes.

Table 1 shows the coefficient values for finger plucked guitar notes.

TABLE I. CORRELATION COEFFICIENTS FOR FINGER PLUCKED SYNTHESIZED GUITAR NOTES

String 1	Open string	Fret 1	Fret 2	Fret 3	Fret 4	Fret 5	Fret 6
Number of samples	70	60	60	140	140	50	50
Correlation	0.9512	0.9596	0.9517	0.9361	0.8079	0.8856	0.9008
	Fret 7	Fret 8	Fret 9	Fret 10	Fret 11	Fret 12	Fret 13
Number of samples	190	50	100	60	60	70	70
Correlation	0.9465	0.9286	0.8689	0.933	0.9303	0.9059	0.9495
	Fret 14	Fret 15	Fret 16	Fret 17	Fret 18	Fret 19	Fret 20
Number of samples	60	70	60	70	130	50	70
Correlation	0.9212	0.8941	0.9576	0.9408	0.941	0.9273	0.8902

Similarly, Table 2 shows the coefficient values for plectrum plucked guitar notes. In this table, we have shown the samples values only for thirteen frets instead of taking all the twenty frets. The twelve frets complete one full octave so we have shown values for that one octave.

TABLE II. CORRELATION COEFFICIENTS FOR PLECTRUM PLUCKED SYNTHESIZED GUITAR NOTES

String 1	Open string	Fret 1	Fret 2	Fret 3	Fret 4	Fret 5	Fret 6
Number of samples	50	190	100	170	300	60	60
Correlation	0.9498	0.9394	0.9452	0.9288	0.9238	0.9442	0.9476
	Fret 7	Fret 8	Fret 9	Fret 10	Fret 11	Fret 12	Fret 13
Number of samples	80	70	60	60	100	260	50
Correlation	0.9177	0.9371	0.9379	0.9293	0.9382	0.9403	0.9295

V. SUMMARY

We estimated the impulse response of the box shaped acoustic guitar notes by using the adaptive cepstral domain windowing approach. In comparison with the methods discussed in section [2], this gives different approach toward the estimation of impulse response of acoustic guitar notes. We did rigorous experimentation with all the twenty frets of total six strings with two plucking styles, finger and plectrum. We have also observed the Linear Time Invariance (LTI) nature of the impulse response by plotting impulse response of all frets of a single string.

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