Piano Sound Characteristics: A Study on Some Factors Affecting Loudness in Digital And Acoustic Pianos

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Abstract

The study of the piano sound characteristics is an essential part on the way of creation of high quality synthesizers and computer music applications. This paper focuses on the loudness property of the piano and on what and how different piano characteristics affect its loudness. This research combines results of other studies about this issue, as well as the authors' experimental study in this field. The aim of such research is to create a relatively simple model which allows calculating the expected loudness of the piano music when it is digitally represented in MIDI. The loudness information can benefit computer music applications like visualizers, automatic music classifiers, and performance study applications.

Key Words : Piano sound, Loudness, Sones, Amplitude envelope.

1. Introduction

The piano is among the foremost instruments in classical music. The sound in acoustic piano is produced by striking a string with a felt hammer. The pianos, and especially the grand expensive ones, are known to produce a very rich pleasing sound [7].

Because of this importance of the piano in music, a lot of researches had been held to understand its tone. Such researches are mainly interesting for enhancing the contemporary pianos like in the case of Stuart pianos[9], or for enhancing the digital piano synthesizers, as well as applications in psychoacoustics and computer music understanding.

This paper is a study on the loudness of the piano sound and some factors affecting this loudness. It aims to create a relatively simple model of estimating the loudness (in sones or dBA) in a digital piano stream (like the popular MIDI representation). [1]

While digital pianos (synthesizers or samplers) convert MIDI commands into a sound wave which resembles the acoustic piano sound in a degree which depends on the quality of the digital piano, computer music applications can perform different analytical tasks on the MIDI stream. For example, in music context analysis like the musical key determination (Parncutt in [8]) the stream is analyzed mathematically in order to determine the key. In performance analysis [10] the dynamics of loudness were studied, the loudness values in sones were obtained by analyzing the sound wave using Zwicker method[5]. Applications for visualization frequently use the perceived loudness as one of the main parameters for the visual implementations [12].

2. The representation of the piano sound in MIDI and the loudness

The piano if compared to other musical instruments has relatively less number of parameters to control by the performer (the pianist); these are the notes, dynamics, and the pedals [1]. However, there are debates whether the dynamics are fully represented by the velocity parameter used in MIDI or the pianists can still control timbre by altering touch [3].

In the digital command stream like MIDI, the pianist actions are represented as notes and pedal commands. The notes commands have 2 parameters: the note number which merely represents the key in the piano keyboard (it has a domain of 127 values enough for the 88 keys of standard piano), and the velocity value which represents the loudness of the note in a domain of 127 values. The pedal commands describes the effect of the sustain pedal, soft pedal and sostenuto pedal.

The loudness is a subjective measure as the human ear is not equally sensitive to different frequencies. The objective measure of sound intensity is the sound

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pressure. This one is usually measured in decibel dB units. As the human ear is less sensitive for lower frequencies, the low frequency domain of the acoustic piano has much heavier and longer strings which radiate more energy and cause higher sound pressure, but not louder perception.

The subjective loudness is usually measured in dBA[2] and then converted to phones or sones. The sone scale is considered to be the best to represent the loudness as it is unlike phones suggests a linear scale for hearing [5].

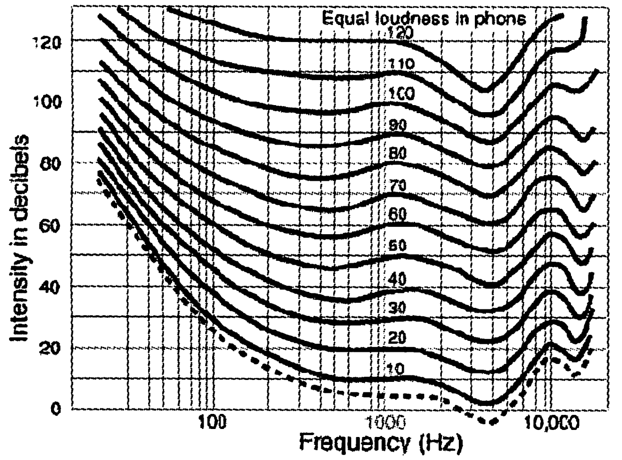

Figure 1. The equal hearing levels

3. The experiment

The authors performed the experiments on Yamaha and Kawai acoustic pianos available in the campus of the University of the Ryukyus, Yamaha AP-60 digital piano sampler controlled by a computer through USB port, and a dBA sound pressure meter Galaxy Audio CM-140.

The experiments aimed to demonstrate what affects the loudness of the instrument and how. In the case of the acoustic pianos, an amateur pianist played single or dyad notes with different dynamic levels, and a sensitive microphone recorded the sound for further analysis. In the case of the digital piano the control was directly through the computer interface with exact velocity values rather than less accurate dynamic levels used in the acoustic piano case. All the experiments paid no attention to the acoustics of the room, or any other external parameters which might affect the loudness as this is not the task of estimating the intended loudness in MIDI. Also the loudness is measured in a distance 80cm from the piano's keyboard (where the pianist's ears are expected to be).

[2] dBA is one of the IEC179 curves. It is the subjective dB value according to the equal loudness of experimental curves in the frequency domain. For example, if 2 simple sinusoidal tones with frequencies 1000 and 100 are causing an equal sound pressure of 80dB, then their dBA values will be 80 and 60 respectively as the 100 frequency tone will sound much quieter.

4. Discussions

Here we will introduce separately the factors studied in this research and the way they affect the loudness of the piano sound.

4.1. The effect of velocity

The velocity is the factor which directly answers for the loudness. The performer changes the dynamic level of the music by valuing the velocity of the pressed keys. The following table (Table 1) shows a relationship between the dynamic levels, digital velocities and the loudness. Similar tables can be found in other researches about the digital piano sound [6].

The dBA was measured by our dB meter, while the sone is calculated by a curve interpolation formula:

$$Sone = 10^{\frac{dBA-28}{33.22}} \qquad (1)$$

Table 1. The dynamic levels in music, their digital velocity equivalent, and peak loudness value both in dBA and sones.

Dynamic	Velocity	dBA	Sone
ff	110 ~ 127	90~95	75~105
f	90 ~ 110	85~90	52~75
mf	75 ~ 90	80~85	36~52
mp	65 ~ 80	75~80	26~36
p	50 ~ 65	65~75	13~26
pp	0 ~ 50	-∞~65	0~13

Figure 2 shows 12 values for dBA and Sones when velocity changes linearly between 20 and 130 (the last actual value was 127). It is possible to infer, with good approximation, that increasing the velocity linearly increases the perceptive of loudness linearly. However, a closer examination for the curves shows that the increasing of the loudness in sones for small velocities is smaller than the increase for the high velocities (Or the curve of the sones is bent to the outer side if compared with the velocity straight line).

The authors suggest the following explanation of this phenomenon: Researches on the string excitation by the hammers [2,3] show that the overtones of a string, vibrating with its fundamental frequency *f*, depend on the initial speed of the hammer. When the hammer strikes the string with higher speed (in case of higher velocity) the string tends to vibrate with higher frequencies overtones, or in other words, the sound of the loud note sounds slightly higher in frequency than the sound of the quiet note. As our ear is more sensitive to higher frequencies, the note sounds even louder. This is especially noticed for the very low domain of the piano keyboard.

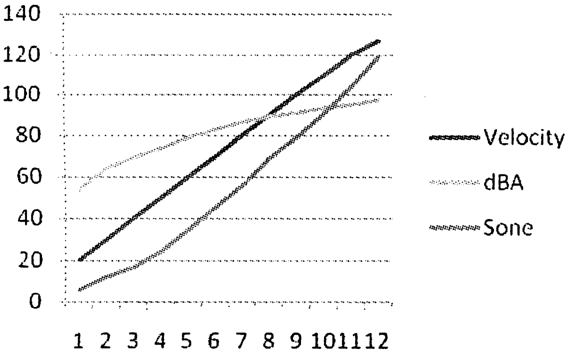

Figure 2. The dBA and sones values for 12 values of velocity between 20 and 130 for note C2

4.2. The effect of note number

When played with the same dynamic level on acoustic piano or same velocities in digital piano, the loudness is invariant to the note number. The strings of the piano are maintained in such a way (by varying density, length and section area) to radiate the same loudness. Although different pianos demonstrated different results, it was difficult to notice some common tendency. As a universal case the authors assume that it is accurate enough to say that same velocities cause the same peak loudness regardless of note number.

4.3. The effect of decay

The peak loudness is the loudness immediately after the attack time (attack time is usually less than 1/10 sec). The attack phase is followed by a decay phase which lasts until the note is released.

The decay is a complex phenomenon in piano sound, and there are quite many researches on this issue. However, for the loudness determination, the decay can be generalized of having an exponential shape like demonstrated in Figure 3.

The loudness during the decay phase can be roughly estimated by the following formula empirically suggested by the authors:

$$S = f(v) \cdot e^{\frac{-t^{0.7}}{h(n)}} \qquad (2)$$

where S is the loudness in sones, $f(v)$is the velocity dependency function (can be estimated from table 2), t is the time in seconds between the peak loudness moment and the desired moment. $h(n)$ is the note number dependency (table 2). This formula clearly reflects the nature of piano sound decay: by increasing the velocity the decay time also increases, and by increasing the note number it decreases [3].

Table 2. Average rounded values in seconds for different notes decay until the loudness is beyond hearing threshold

Velocity / Note	c1	c3	c5	c7
v=80	25	20	15	10
v=40	20	15	10	5
v=127	30	25	20	15

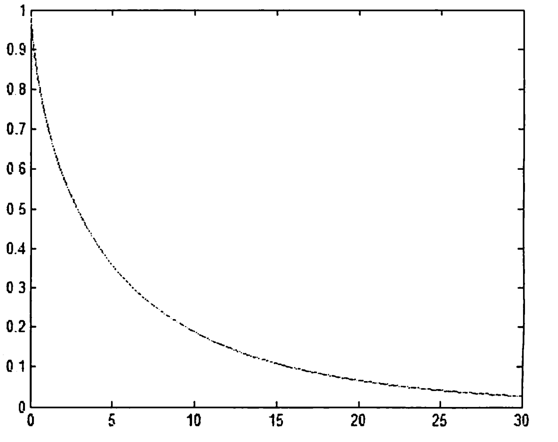

Figure 3. A general decay from the initial level at peak loudness to hearing threshold for note C2.

4.4. The effect of releasing

The release phase starts when the damper mutes the vibrating string. This happens as a result of piano key and pedal being released. The sound is muted within a short time (usually less than 0.5 seconds). The model for the release phase can also be approximated as an exponential one in which the value achieves a loudness beyond threshold of hearing within fixed time interval (around 0.5 seconds). The highest octave or so in the piano keyboard has no dampers, and thus, there is no releasing phase for them.

4.5. The effect of soundboard and polyphonic notes

The soundboard in the piano is responsible for a very significant part of the sound radiation. The response of the soundboard was studied in many researches [6]. It was shown through many works that the response of the soundboard is linear with good approximation. This means that the summation of two separate notes sounds similar to their dyad. However we noticed that the decay time for the notes of the dyads is not the same as the decay time for these same notes if they were played separately with the same velocity.

The decay time for a dyad of notes with an interval of semitone or one tone is less than the decay time of a dyad for which notes have an interval of an octave. Although this fact is interesting for studying the piano sound characteristics, it might be too small to be considered in the loudness task.

4.6. The effect of pedal, Ribattuto and other effects

Among the popular piano pedals (soft, sostenuto, and sustain) the sustain pedal is certainly the most important one. It releases all the strings by removing all dampers, and as a result affects the sound of the piano greatly. All the strings start vibrating a little when any string starts vibrating as it transmits energy to them through the common soundboard. Most digital pianos (including our Yamaha AP-60) do not change the sound quality if the sustain pedal is applied. They simply delay the release phase of the notes till the pedal is released without making any changes to sound.

The Ribattuto effect takes place when the same note repeatedly pressed while the sustain pedal is applied. In acoustic pianos this can make the note sounds much louder than its initial value. Most digital pianos however, ignore this effect.

There are still other piano characteristics which can still affect the loudness and are interesting for its study. For example, if you gently press a low note (to rise the damper and free the string without causing sound), and strike shortly and strongly some other high note, a low quiet frequency sound of the low note will be heard as the energy of the higher string will be transmitted through the soundboard to the free string. This effect is usually also ignored in most digital pianos.

5. Conclusions and further work

The paper extracted 8 different factors which affect the loudness in acoustic and some digital pianos. Some of these factors were studied enough in a sense to create a quantitative model (effects of velocity, note number and decay), while other factors were studied generally without suggesting a quantitative model to include them in the digital piano loudness model. A further study of this research is expected to cover in more details the other factors mentioned above. This research is expected to result in an accurate loudness calculating tool for the piano sound in MIDI files. This tool will be an important addition to the music software especially such ones like visualizers, music classifiers, performance analyzers, and others.

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