Basic Concept of the Data base on Music and Sound - I: Examples of Frequency Analysis -

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ABSTRACT

Some effects of music and sound flooding the streets on people are positive, such as music therapy, and others are negative, such as earphone hearing loss. In our laboratory, the authors are studying the construction of a data base for effective use of sound and music, while they are continuing to evaluate various effects of sound and music on humans quantitatively. After physically express sound and frequency analyses to Japanese nursery rhymes "Akatonbo" and Debussy's "Moonlight", the effects of music and sound were discussed, and the policy of the data base construction was proposed. These music have the spectrum similar to that of natural sound, and make many people calm or refreshed. By constructing the data base, it is possible to calculate how much the earphone users are exposed to the sound energy from the information such as the music genre that the earphone users listen to.

Keywords: Effects of sound and music to human, Spectrum, Earphone hearing loss, Music therapy, Frequency.

1. INTRODUCTION

In modern society, music and sound are everywhere. It is quite easy to obtain music and sound through PCs or smartphones. On the other hand, people often do not care what the sound or the music is.

People can enjoy listening to music and sound, but on the other hand, they can be exposed to noise or noisy music and become deaf or neuroses. If you keep listening to your favorite music on a daily commuter train at a relatively high volume, you may get hearing loss [1,2]. It is quite meaningful to evaluate the effects of music and sound on humans quantitatively or to use music and sound effectively while avoiding dangerous music and sound.

The effects of music and sound on humans include, for example, psychological effects on the mind or brain as information, and physiological or physical effects on the body as energy. In our laboratory, we are studying various effects of music and sound on human beings, and are studying specific ways to use them effectively. In parallel, our laboratory is collecting spectral data of music for the purpose mentioned above.

In this paper, how to construct the spectrum data base of music and sound is explained, and how to use it is proposed. In addition, some of the spectrum data of the music that we actually collected are introduced and how to classify them is discussed.

2. MERITS AND DEMERITS OF SOUND AND MUSIC

Sound

Sound gives us various kinds of information. The doorbell will let you know that a visitor has arrived. Warnings, such as sirens from ambulances or police car, can give an indication that an accident or incident has occurred nearby. Sound is also useful in non-destructive testing, as the sound changes as the crack initiate or propagate in the material. A good engineer can understand the condition of a machine or device by listening to it.

On the other hand, noise at construction sites is not only a pleasant sound, but also it will cause hearing loss if you continue to listen to it. Even if people are not particularly sick, physically or mentally abnormal, they may have a resistance to

the voice of the person whom they dislike, whom they are not good at, or who is their boss. There is also physiologically unacceptable sound, such as scratching the glass with nails. A sound below 20 Hz, which is the lowest frequency of human audible sound, is perceived not as sound but as vibration, and causes physical discomfort. The authors suspect that the discomfort of sound may be related to the danger that humans should avoid, but of course it has not been proved.

Music

For example, I hear that some hospitals use music that their patients like as background music to free them from the fear of being trapped in a closed space when undergoing MRI and other tests. Many hospitals offer music concerts for patients who cannot go out, for examples a birthday party, a part of a local event, and so on. There are many situations where music therapy is used for the person who has mental stress or injury. It is not uncommon to see the scene that athletes listen to the music alone using earphones in order to calm themselves before the competition. It is said that music is good for children's emotional education. The rhythm played by the human body may brainwash themselves with the wonder of music, after they listen to their mother's heart sound when they were growing up on their mother's womb and to their own heart sound. In any case, the authors believe that music is a gift from God whose essence is well unknown.

Such music is not versatile, such as not valid for all purpose or for all people. For an example, listening to booming music such as marching music when feeling depressed may cause a rejection reaction. Sometimes, too much attention is paid to music, which results in carelessness and an accident. Participation in loud live concerts poses a risk of hearing loss. Furious fans of music often choose the conductor and the orchestra, such as Beethoven's symphony No.9 with Karl Böhm and Vienna Philharmonic Orchestra, and cannot enjoy, sometimes cannot accept, the music by other performers. People have their favorite music and do not like some other music. Music which one person feels good or likes is not always a good music for other person. The fact is remains the biggest bottleneck in music therapy and music prescription concept. There are many unclear principles and reasons for music. The authors wonder that the practical application such as entertainment in music field is ahead of research of that.

3. PHYSICS OF SOUND AND MUSIC

Physics of pure tone

Eq. (1) shows the motion equation of particle vibration in consideration of the restoring force (the first term on the right side), the resistance force (the second term) and the external force which vibrates (the third term), where m is the mass of the particle, x is the displacement of the particle, t is time, k is linear coefficient related with the restoring force, γ is linear coefficient related with the resistance force.

$$m\frac{d^2x}{dt^2} = -kx - 2m\gamma\frac{dx}{dt} + F_0\sin(2\pi\beta t) \quad \cdots\cdots \quad (1)$$

Assuming that the resistance force and the external force are not working, Eq. (2) of simple oscillation is obtained as the solution of Eq. (1).

$$x = A\sin(2\pi ft + \theta) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (2)$$

The normal steady sound having the frequency f and the amplitude A is represented by Eq. (2). Here, θ is phase difference, which can be regarded as 0 under the definition that an instrument starts to vibrate at the initial time when it is played. In addition to aerophones [3], a chordophones [3] that produces a sound by vibrating a string with a bow, and electrophobe [3] produce a steady sound.

Physics of decaying tone

Assuming that the external force is not working, Eq. (3) of decaying oscillation is obtained as the solution of Eq. (1) under the condition of $\omega > \gamma$, when damping progresses while vibrating.

$$x = Ae^{-\gamma t}\sin(2\pi ft + \theta) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

The normal hammering sound having the frequency f, the amplitude A and damping coefficient γ is represented by Eq. (3). Here, θ is phase difference, which can be regarded as 0 under the definition that a instrument starts to vibrate at the initial time when it is played. In addition to percussion instruments (idiophones and membranophones) [3], chordophones [3] that produces a sound by striking or hitting strings produce a hammering sound.

Sound Energy flux

The energy flux ϕ [J/m$^2\cdot$sec] of the sound wave which is transmitted in the space of density ρ [kg/m^3] at speed c [m/sec] and whose amplitude is A [m] and frequency is f [Hz] [4] can be calculated by Eq. (4).

$$\phi = 2\pi^2\rho cA^2f^2 \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

The energy density Φ [J/m^2] of a stationary sound can be obtained by simply multiplying the energy flux ϕ calculated using Eq. (4) by the pronunciation time t [sec]. On the other hand, the energy density Φ [J/m^2] of an hammering sound can be obtained by time integration of the energy flux ϕ as shown the follows when the impact time is 0 [sec].

$$\Phi = \int_0^\infty \phi dt = \int_0^\infty 2\pi^2\rho c(Ae^{-\gamma t})^2 f^2 dt$$

$$= \frac{\pi^2\rho cA^2f^2}{\gamma} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (5)$$

Damping coefficient of the piano

The scale musical instruments which product hammering sound include the piano, the harp, the celesta, the harpsichord and so on.

When the 440Hz A note (No. 49 note, A4) of the piano is actually tapped with normal strength (*mf*), the amplitude reaches its maximum immediately after tapping, drops to 35% to 40% in the first 0.11sec, and drops to 10% to 15% in 0.45sec, then keeps ringing for a while, although it attenuates slightly [5]. This is a characteristic of the piano instrument, which relates to resonance and overtones. Therefore, the experimental result cannot be simply compared with Eq. (3) while good agreement between the experimental result and Eq. (3) in the first 0.2 seconds after pronunciation can be obtained with the damping coefficient of about 10. The sound of the piano, which can be represented by Eq. (6) is a composite sound containing overtones each of which has a different damping coefficient in addition to frequency and amplitude.

$$x = \sum_i A_i e^{-\gamma_i t}\sin(2\pi f_i t) \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (6)$$

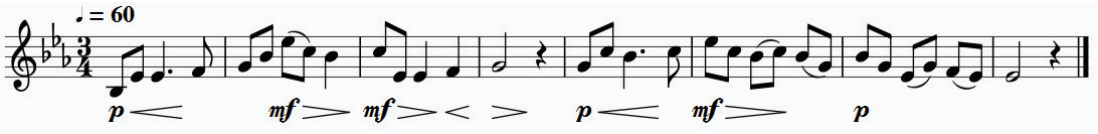

Fig.1: Musical score of Japanese nursery rhyme "Akatonbo".

Table 1: Primary analysis of "Akatonbo".

音名		f[Hz]	音番号	音の並び	拍数, n
ヘ音譜表ハ	ハ	130.81278	28		0
	嬰ハ	138.59132	29		0
	ニ	146.83238	30		0
	嬰ニ	155.56349	31		0
	ホ	164.81378	32		0
	ヘ	174.61412	33		0
	嬰ヘ	184.99721	34		0
	ト	195.99772	35		0
	嬰ト	207.65235	36		0
	イ	220	37		0
	嬰イ	233.08188	38	1	1
	ロ	246.94165	39		0
中央ハ	ハ	261.62557	40		0
・	嬰ハ	277.18263	41		0
・	ニ	293.66477	42		0
・	嬰ニ	311.12698	43	2 3 4 5 14 15 16 39 42 43 43 43 43	13
・	ホ	329.62756	44		0
・	ヘ	349.22823	45	6 17 18 41	4
・	嬰ヘ	369.99442	46		0
・	ト	391.99544	47	7 19 20 21 22 25 36 38 40	9
・	嬰ト	415.3047	48		0
・	イ	440	49		0
・	嬰イ	466.16376	49	8 11 12 27 28 29 33 35 37	9
・	ロ	493.8833	49		0
ト音譜表ハ	ハ	523.25113	49	10 13 26 30 32 34	6
・・	嬰ハ	554.36526	49		0
・・	ニ	587.32954	49		0
・・	嬰ニ	622.25397	49	9 31	2
・・	ホ	659.25511	49		0
・・	ヘ	698.45646	49		0
・・	嬰ヘ	739.98885	49		0
・・	ト	783.99087	49		0
・・	嬰ト	830.6094	49		0
・・	イ	880	49		0
・・	嬰イ	932.32752	49		0
・・	ロ	987.7666	49		0
上のハ	ハ	1046.5023	49		0

拍数, N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
周波数, f[Hz]	233	311	311	311	311	349	392	466	622	523	466	466	523	311	311	311	349	349	392	392	392	392	0	0	392	523	466	466	466	523	622	523	466	523	466	392	466	392	311	392	349	311	311	304	297	291	0	0

The sound of the piano actually describes a more complex time history due to the action of the sound board and other resonant strings.

4. ANALYSES OF MUSIC

Analysis of simple song

The Japanese nursery rhyme "Akatonbo" (it means "red dragonfly") is analyzed for an example of simple song. The musical score is shown in Fig.1, which consists of eight measures and thirty-one notes. As it can be seen, it has various performance instructions, such as crescendo, forte and slur.

Primary analysis of simple song

To make it easier to analyze the score, it was reproduced to the table where the number of beats is taken in the horizontal direction and the pitch is taken in the vertical direction shown as Table 1. By adding this table horizontally, it is possible to count the number of beats of the pitch of each frequency. Fig.2 shows the results of counting. It is a histogram corresponding to the spectrum, although changes in speed and strength during performance are not considered. It can be seen that the music has relatively small number of beats of treble, has only one beat of the lowest note, and is on the base sound of 311.1 Hz. This feature is similar to that of the sound in nature, and it may be inferred that people can relax by listening to the music.

Secondary analysis of simple song

Based on Table 1, Fig. 3 can be drawn where the horizontal axis represents the number of beats and the vertical axis represents the frequency. If the frequency analysis (Fourier

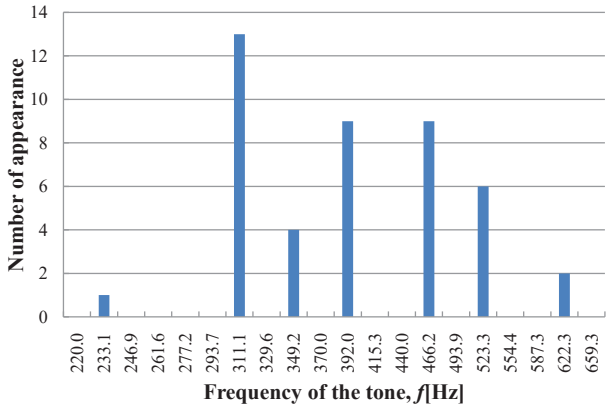

Fig.2 : Beat numbers of each frequency pitch on "Akatonbo".

Transformation) is performed on the frequency fluctuation, the intonation of this melody can be discussed. As an example, the intonation in which a long-term fluctuation with 210 beats as one cycle, a medium-term fluctuation with 21.5 beats as one cycle and a short-term fluctuation with 9 beats as one cycle are mixed in a ratio of 80:160:65 is drawn as a curve in Fig.3.

On the other hand, there is no clear knowledge about the psychological effects of intonation on humans.

Analysis of larger song

Next, as an example of classical music, "Moonlight" composed by Debussy was analyzed. The analysis which provides the result as shown in Fig. 2 may be carried out, but the task of checking each note from the musical score takes a

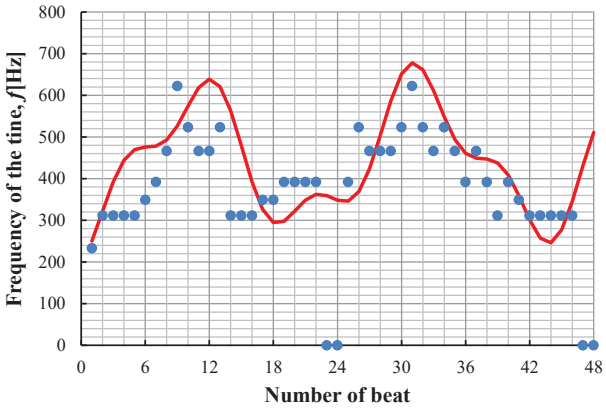

Fig.3 : Frequency time history of tones on "Akatonbo".

considerable amount of time. While this target is a solo piano music, the time required will be enormous if you analyze orchestra music. Therefore, another analysis, which is essentially the same analysis to obtain the result as shown in Fig. 2, should be considered.

Since the result of Fig. 2 is essentially that of frequency analysis, perform frequency analysis of the entire music was performed. Fig. 4 shows the frequency analysis result. The reference volume was the minimum volume of the sound source. That is, the amplitude of 0 dB or less means that the sound of corresponding frequency does not exist. The base frequency was 117Hz, and the maximum frequency was 5013Hz. A spectrum was confirmed that drew almost linearly during the period from 117Hz to 5013Hz. This music also has spectral characteristics similar to that of natural sound, and is presumed to be comfortable to listen to.

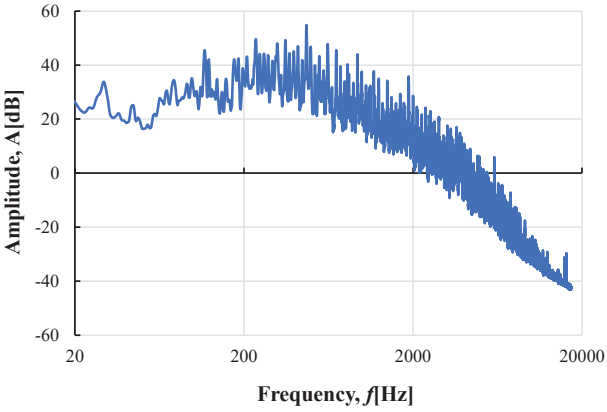

Fig.4 : Result of frequency analysis to "Moonlight" by Debussy.

4. DISCUSSIONS

Data base format

When making music into a data base, it is usually done in the form of score or sound data, for an example WAVE data. Although a method of constructing a data base with only them can be considered, they cannot be used directly for classification and analysis.

When evaluating the physiological (physical) effects that sound and music have on humans, the energy that they have are significant. The sound energy is proportional to the square of the pitch (frequency) and the volume (amplitude), and the energy can be calculated if the frequency characteristics shown in Fig. 2 and Fig. 4 are known. On the other hand, when evaluating the psychological effects of sound and music on people, the pitch and volume are important indicators. From the previous researches and the past results and experiments by the authors, it is generally felt that the high frequency gives the awakening effect and the low frequency gives the sedative effect. The data base of sound and music should valuably consist of also the frequency characteristics such as spectrum in addition to the music scores and sound data such as Wave data, Midi data.

Data base construction method

The energy of hammering sound produced by the piano or the metallophone is different from that of stationary sound produced by the vocal or the flute, even if the volume and the note length are the same. Since the hammering sound is quickly attenuated, considering that the energy is proportional to the square of the volume, the energy of the first attack portion is dominant.

The result shown as Fig. 2 is more accurate than that shown as Fig. 4, but the time required to obtain the result of Fig. 2 is significantly longer than the time to obtain that of Fig. 4. The software [6] can count the number of each note in each pitch from the Midi data of the music as the input data, which provides the result close to Fig.2. The method cannot be applied to stationary music or sound since it cannot take the note length into consideration.

Data base utilization policy

For an example of applying a data base to consider the adverse effects of sound and music on the body, what kind of music has been listened to by the earphones must be the important information in order to study the structure and function of earphones to prevent hearing loss [1]. Since detailed recordings of information such as volume at that time, listening time, and directly how high-frequency components are included, cannot be expected, it is necessary to have a data base that allows to infer the sound energy received so far from the favorite composer, genre, and so on. In addition, in order to clarify the mechanism of music therapy and to establish a specific music selection method that eliminates stress in hospitals and daily life, it is necessary to find a correlation between the characteristics of music and psychological evaluation values such as comfort. It should be the data base that can be flexibly analyzed in various ways to find out what musical characteristics are needed.

In modern society, where new music and sound are created every day, it is not possible to concrete a data base of all music and sound all over the world. Therefore, it is also important to infer unknown sound and music characteristics from a certain data base. Therefore, the authors would like to classify the data by grouping or clustering, while learning big data with artificial intelligence would also like to be considered in the future. The system which can immediately estimate the spectrum as the output based on the input the information, such as composer, genre, and instrument, of the unknown music to be used right now, or the system which can reverse deduce what kind of music is suitable for the present request as the input, is expectedly proposed.

Aiming for an ideal image in the future, it would be planned to collect the score, the sound data, and the spectrum analysis results of as various and many music and sound as possible.

5. CONCLUSIONS

While sound and music are effective, they can be dangerous or disturbing. In order to use music and sound effectively and avoid the adverse effects of those, it is essential to evaluate quantitatively the effects of music and sound on people and to develop the evaluation method. In this paper, some equations that physically express sound were confirmed, the effects of music and sound were discussed, and the policy of the data base construction was proposed with the examples of Japanese nursery rhymes “Akatonbo” and Debussy's “Moonlight”. In addition to the following conclusions, various questions, uncertainty and issues would be challenged to be solved in the future.

1) Both the Japanese nursery rhyme “Akatombo” and Debussy's "Moonlight" may be the music for people that calms or refreshes their mind. Frequency analysis of these revealed that their spectrums were close to that of natural sound. Given that natural sound are pleasing to living things, it is clear why these music are pleasant for human to listen to.

2) In studying the influence of music on humans, there are various kinds of necessary information such as spectrum and intonation of melody, that is, time history of pitch. Since only the God knows what kind of music characteristics are required in consideration of earphone deafness prevention and application to music therapy, etc., the authors collect various sound and music scores, sound data, spectrum as much as possible.

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