Chord Character Evaluation Model Based on Harmoniousness: Application to Music Mood Visualization Interface

Eriko Aiba
National Institute of
Advanced Industrial Science and Technology
(Japanese Society for the Promotion of Science)
Osaka, Japan
Email: aiba.eriko@aist.go.jp

Kensuke Tobitani
School of Science and Technology
Kwansei Gakuin University
Hyogo, Japan
Email: tobitani@kwansei.ac.jp

Takayuki Shimotomai
Brain Science Institute
Tamagawa University
Tokyo, Japan
Email: shimotomai@lab.tamagawa.ac.jp

Mitsuaki Tani
Graduate School of Science and Technology
Kwansei Gakuin University
Hyogo, Japan

Noriko Nagata
School of Science and Technology
Kwansei Gakuin University
Hyogo, Japan
Email: nagata@kwansei.ac.jp

Takashi X. Fujisawa
Graduate School of Biomedical Sciences
Nagasaki University
Nagasaki, Japan
Email: fujisawa@nagasaki-u.ac.jp

***Abstract*—The chord, along with melody and rhythm, is one of the important elements in constituting music, but the cause of music's psychological effects are, for the most part, yet to be clarified. There are previous studies that define chord characters on the basis of the levels of dissonance, tension and modality, but there is not enough research to discuss psychological indexes which is called chord's "brightness." Therefore, in this study, in order to define a chord character evaluation based on harmoniousness, we propose a method for estimating the impression of brightness in chords. Evaluation experiments were performed in order to validate the proposed method. As a result, a strong correlation was found between the proposed degree of harmoniousness (H) and the results of psychological experiments. Furthermore, through the application of these results, an interface for representing musical mood through color was developed.**

I. Introduction

The chord, along with melody and rhythm, is one of the important elements in constituting music, and as such, it is one of the most essential factors needed in order to evoke various emotions through music. Various impressions brought about by the chord are influenced by the sound that constitutes it, and this unique feature is seen in every chord. For example, a major chord brings an impression of consonance (a combination of notes that sound pleasant to most people when played at the same time), while diminished or augmented triads give the impression of dissonance. This is a common reaction regardless of cultural or social background, and has been a widely used technique not only in things such as film background music but also in soundscapes and sound design for media transmissions.

Many psychological models have been proposed (cf.[1], [2], [3], [4]) on the relationship between physical characteristics (such as tone frequency ratio) and psychological characteristics of chords. However, these studies have largely been restricted to the most fundamental chord group (triads), and a model that can be fully explained is yet to be constructed.

Of particular interest regarding chords, is the impression of "brightness." A major chord generally assumed to be "bright," while minor triads sound noticeably "darker." It has been reported that even three- to four-year-old infants can distinguish these differences[5], therefore this cognitive ability seems to be innate. However, the physical quantities to distinguish these differenced are yet to be understood. Furthermore, the "brightness" in visual perception is considered a fundamental mechanism of biological organisms[6]. Therefore this is one of the important issues that relates to multi-sensory perception (Why it also occur in auditory perception?) and vocal tone with the transfer of emotion.

In this study, we investigate the "brightness" which is assumed to be one of chord impressions, propose a new chord character evaluation model based on harmoniousness, and assess the validity of these elements through psychological experimentation. Furthermore, based on the proposed model, we have developed an interface to express musical mood with colors.

II. Conventional Chord Character Evaluation Model

The fundamental ideas for a chord character evaluation model can be roughly divided into two systems. One is based on the physical factor that the tone components of a chord have a harmonic (at least approximately) relationship with a basic tone. Terhardt was a particular advocate of this concept, calling it harmony and distinguishing it from consonance [7].

978-1-4673-2743-5/12/$31.00 ©2012 IEEE

The second idea involves the beat or rough feeling arising from slight frequency difference between the constitution tones of a chord or the overtones of the constitution tones, and these bring about a sense of dissonance. This concept was proposed by Helmholtz[8], and Plomp and Levelt (1965) quantified this sense obtained from the interval of two tones as the dissonance level[1].

The chord character evaluation model proposed by Cook and Fujisawa was also based on the second idea[9]. Cook et al. defined chord character as the "general nature of sensibility given by chords." They also calculated a theoretical curve for psychological indexes such as the levels of dissonance (D, consonant-dissonant), tension (T, tensed-calm), and modality (M, major-minor), with reference to the frequency ratio of the two interval structures (a root note to a third tone, a third tone to a fifth tone) that compose a triad. Each equation is shown below:

$$D = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1} v_{ij}\alpha_3[exp(-\alpha_1 x_{ij}^{\beta}) - exp(-\alpha_2 x_{ij}^{\beta})] \quad (1)$$

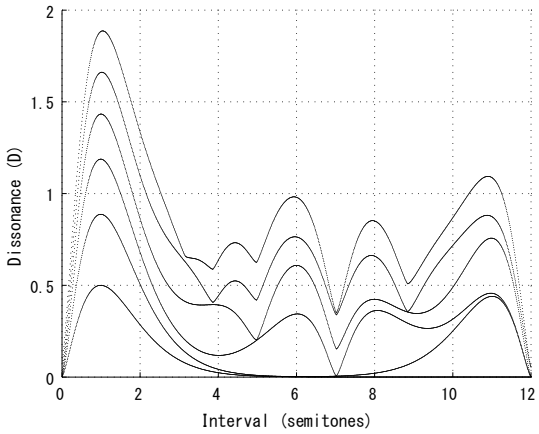
$$T = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\sum_{k=0}^{n-1} v_{ijk} exp\Big[-\Big(\frac{x_{ik}-x_{ij}}{\gamma}\Big)^2\Big] \quad (2)$$

$$M = \sum_{i=0}^{n-1}\sum_{j=0}^{n-1}\sum_{k=0}^{n-1} -v_{ijk}\Big[\frac{2(x_{ik}-x_{ij})}{\epsilon}\Big] exp\Big\{-\Big[\frac{(x_{ik}-x_{ij})_{ijk}^4}{4}\Big]\Big\} \quad (3)$$

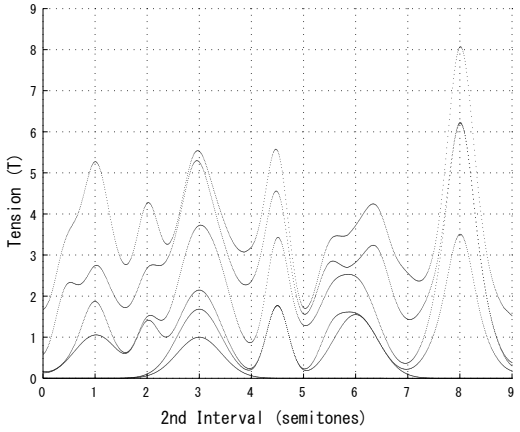
Here, α, β, γ and ϵ represent constant values, x is an interval, n is the number of harmonic overtones used in the equation, and v is volume.

The expanded theoretical curve shown in Fig.1(a), (b) and (c) are obtained by adding up each overtone to six harmonic overtones. The intervals between the root notes and the third tones in Fig.1(b) and (c) are all five semitones.

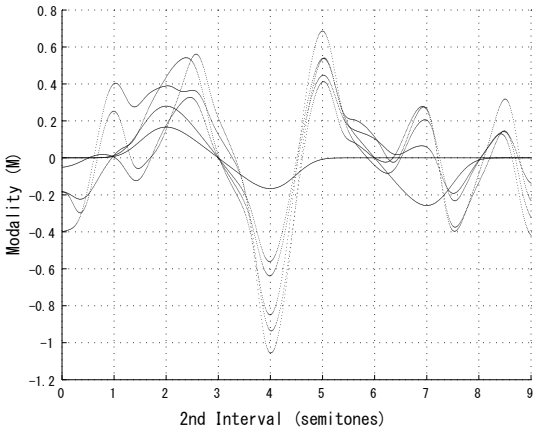
In the psychological indexes, the instability obtained from combining the dissonance level and tension level is reportedly similar to the results obtained from the behavioral experiment, revealing the human impression effect against chords. However, the modality which is the closest index to "chord brightness" of this study still had problems such that the augmented triad, diminished triad, and suspended fourth were calculated as chords having the completely same modality level. We focused on the harmoniousness of the constitution tones of the chord. We considered a new index of the chord character to be a physical quantity and suggested chord character evaluation models leading to the relationship between the physical quantity and "chord brightness" (psychological quantity) and thus evaluated its validity.



(a) Dissonance Curve



(b) Tenstion Curve



(c)Modality Curve

Fig. 1. Psycholphysical Function of Chord Perception

III. HARMONEOUSNESS

A. Chord Tone Brightness

A chord generates a specific impression based on its types (ex. major triad, minor triad, and augmented triad etc.). In particular, a chord is generally evaluated through "chord tone brightness." More specifically, it was well known that a major triad gave a "bright" or "pleasant" impression, while a minor third brought a "dark" and "sad" impression. The interval composed of two tones does not evoke these emotions, but

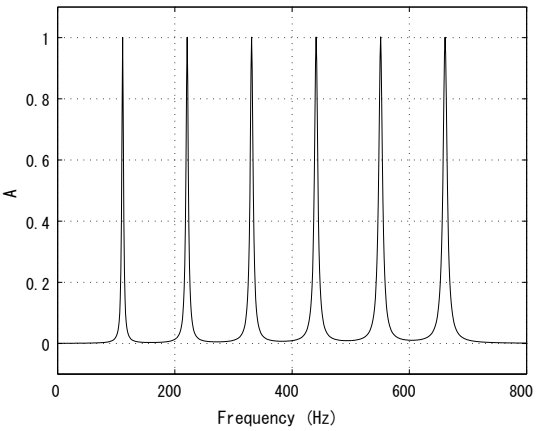


Fig. 2. Approximate Function From Weighting of a Harmonic Overtone

the chord composed of three tones does. A concrete explanation for this phenomenon was not found. However, musical elements such as the Pythagorean scale were considered as having a relationship with the simplicity of the frequency rate. Although the interval between two tones was mainly used as an index in the conventional chord character evaluation model, such a method cannot quantify the relationship among the frequency ratios of three tones composing a chord. Our study solved these issues by using an approximate function for calculating the level of how close a chord tone composed by three or more tones was to a simple integral rate, and we suggested a "chord brightness" modeling method for humans.

B. Definition of Harmoneousness

Harmoniousness in this study reflects the degree of simplicity or proximity in the frequency rate of a chord tone. In order to calculate harmoniousness $f(H)$, we used a weighted approximate function $A(x, f_0)$ carried out near the harmonic overtone of any tone f_0 (Fig.2). The equation of the approximate function $A(x, f_0)$ is shown below:

$$A(x, f_0) = \sum_i \frac{1}{1 + \frac{N(x - if_0)^2}{f_0}} \tag{4}$$

N represents a constant value for changing each spread of the peak composing a comb shape.

The f_0 in the approximate function $A(x, f_0)$ is gradually changed to obtain an integrated value with $f(x)$, which is a frequency spectrum of the chord, and set it as similarity $R(f_0)$. When the similarity $R(f_0)$ is at its maximum, it is defined as harmoniousness H. Each equation is shown below.

$$R(f_0) = \int f(x)A(x, f_0)dx \tag{5}$$

$$\tilde{f_0} = arg_{f_0} max R(f_0) \tag{6}$$

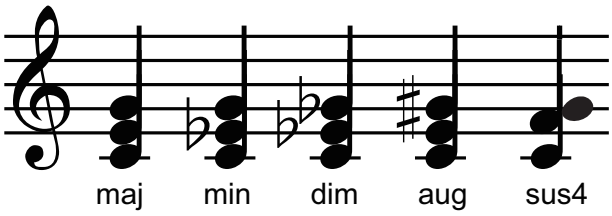


Fig. 3. Principal Triads

TABLE I
CALCULATION RESULT OF HARMONIOUSNESS

Chord	maj	min	dim	aug	sus4
Comp.1(Hz)	261.6	261.6	261.6	261.6	261.6
Comp.2(Hz)	329.6	311.1	311.1	329.6	349.2
Comp.3(Hz)	392.0	392.0	370.0	415.3	392.0
f_0	65.3	130.7	61.7	65.9	130.7
H	0.6992	0.6626	0.3842	0.4261	0.6627

$$H = R(\tilde{f_0}) \tag{7}$$

C. Resulting Calculation of Harmoniousness

TableI shows the results of each and the harmoniousness in the principal triad (Fig.3) ($N = 40$). Harmoniousness decreased in the order of maj>sus4=min>aug>dim. When calculated using the function for modality by Cook et al., harmoniousness lowered in the order of maj>sus4=dim=aug>min, showing a completely different result. We conducted an evaluation experiment for "chord brightness" in five kinds of triad patterns in order to evaluate the validity of the model.

IV. MODEL EVALUATION EXPERIMENT: THE PAIRED COMPARISON OF PRINCIPAL TRIADS

A. Experiment

The paired comparison method was utilized in order to verify the validity of the proposed degree of harmoniousness (H) using the five kinds of triads shown in Fig.3 as an experimental stimulus. As we needed to provide two continuous chords in the paired comparison method, we unified the root note as C (261.6 Hz) in order to suppress the impression evoked by chord progression, or what is known as an order effect, as much as possible. We also added C1 (523.2 Hz), an octave above the root note, to avoid the effect caused by the differing heights of fifth tones. There were twenty stimulation pairs in total. The chord stimulations were generated by piano using MIDI. We played them on a PC via an amplifier and speaker. The subjects consisted of twenty-one university students from ages twenty-two to twenty-five. "Brightness," one of the chord impressions, was evaluated in five steps ("the former chord was brighter," "the former was slightly brighter," "almost the same," "the latter chord was slightly brighter," and "the latter chord was brighter.") Haga's procedure [10], modified from Scheffe's Paired Comparison, was used for analysis.

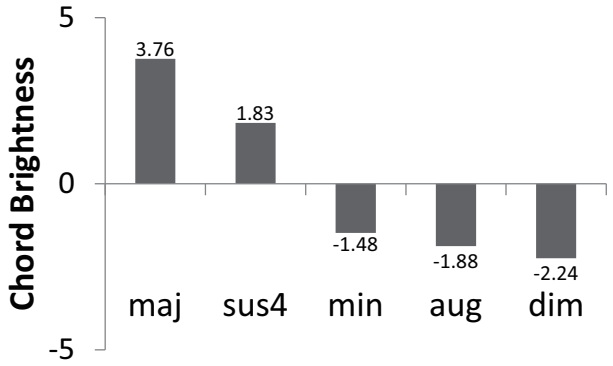


Fig. 4. Evaluation Results of Chord Brightness

B. Results and Discussion

Fig.4 shows the experimental results. These revealed that the chord brightness was maj>sus4>min>aug>dim. This result matched comparatively well with the harmoniousness order calculated in section III-C. The rank correlation test showed no significant correlation between the chord brightness evaluations of each chord from our psychological experiment and the values calculated by the modality function in conventional model ($\rho = 0.2$, $p > 1$, rank correlation test). However, the test showed a strong correlation with our evaluation model base with regard to the harmoniousness suggested in this study ($\rho = 0.97$, $p < .01$, rank correlation test). This result strongly supported the validity of our model.

V. Interface for Music Mood Color Representation

A. Visualization of Music

The studies in visualization of music mood are roughly classified into two, one focusing on global structures such as the overall composition of one phrase and the other focusing on local structures such as with in a measure. For example, "Shape of Songs" shows the global visualization of a musical piece's structure with the overlap of a semicircle from the refrain portion of a melody[11]. The latter visualizes the local mood for an input such as a MIDI sound source, but the hue is mainly assigned categorical to the scale in the composition or tonality[12].

Thus, the following two problems often emerge. The first problem pertains to how the tonality concept should be considered. The tonality concept strongly reflects musical elements (especially in Western music); yet, many non-musicians do not pay attention it. The second is that the evidence for mapping tonality and hue, except in particular cases such as synesthesia (colored hearing)[13], is yet to be obtained.

Therefore, in this study, we used not only the results of color and chord mapping obtained from the calculated results of the chord character evaluation model and the psychological experiment, but also the tonality concept for music and color mapping based on colored hearing synesthesia.

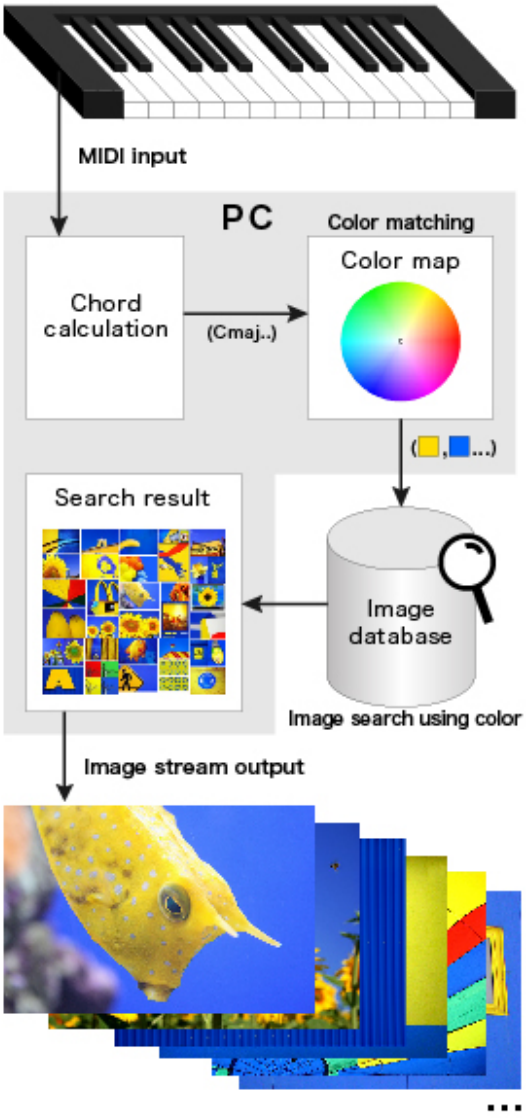


Fig. 5. System Diagram

B. Mapping for Color Space

By assigning each of the three indexes of a chord structure to any color space, we have created an interface for expressing musical mood by color. HSL was used for the color space. The HSL color space consists of three elements, Hue (H), Saturation (S), and Lightness (L). These elements are often used as an alternative to the RGB color space as a result of being considered closer to a human being's actual color perception.

The psychological experiment in the previous study suggested[14] that if the dissonance level (D) increased, the color saturation to be imaged also increased. We had the dissonance level correspond with the saturation. We also had harmoniousness (H) correspond with brightness, because if the chord was bright and high in harmoniousness (H), the

978-1-4673-2743-5/12/$31.00 ©2012 IEEE

color lightness to be imaged also increased.

As the hues were the circulating values, which differed from the saturation or lightness, we first divided them into color classes. We used the PCCS (Practical Color Coordinate System, Japan Color Research Institute, 1964) as the standard for dividing them into color classes. We selected red, orange, yellow, yellow-green, blue-green, blue, blue-violet, and red-violet colors because yellow-green, yellow, orange, and the like were mapped for chords, such as maj or sus4, which were evaluated as bright by previous psychological experiments[14], and red, blue-violet, blue, and the like were mapped for the dim, min, or aug. Regarding the tonality concept, we assigned the tonality for each portion of a music to a color using a tonality-color mapping of synesthesia[15].

C. M-CUBE Function

We constructed a new visualization system (M-CUBE+) that expresses the music mood with differences in color.The system was implemented using Max/Msp/Jitter. The system diagram is shown in Fig.5. The system consists of four modules, chord calculation module, color matching module, image search module and image output module. At first, the value of each chord character was calculated using a MIDI signal in chord calculation module. In color matching module, one or two colors corresponding to the calculated chord are assigned. The key is also assigned a corresponding color. In image search module, the module explore images in Flickr image database using these multiple assigned colors with Flickr API. Finally, the image stream in search results are output in various ways. Thus, the interaction between sounds and screen images were realized by real-time output of the images searched for assigned color in its specification.

VI. Conclusion

This study proposed harmoniousness (H) for evaluating chord characters using chord brightness as an index in the Chord Character Evaluation Model instead of using modality (M). We also evaluated the validity of our proposed model through psychological experiments. The results showed that the proposed model might express evaluations of chord brightness in humans. These results had a high validity with regard to the tone brightness order, but there remains room for improvement because the differences between maj to sus4 and min were relatively small.

In the future, we aim to build a model that is able to evaluate chords consisting of more continuous frequencies (such as chords using microtones). If the physical factors can be evaluated precisely with this model (if humans can sense tonal brightness from the chord with such factors), we will build a model that may recommend a favorite musical piece, suggest music that the listener wants to hear based on musical impression, or an automatic compositional system.

Although this system targets a single chord for evaluation, the chord's impression after progression may be influenced based on the progression of the harmony. Taking this into consideration, we also aim to build a model closer to a human's chord perception.

References

[1] R. Plomp and W. J. Levelt, "Tonal consonance and critical bandwidth," *J Acoust Soc Am*, vol. 38, no. 4, pp. 548–60, 1965.

[2] A. Kameoka and M. Kuriyagawa, "Consonance theory part i: consonance of dyads," *J Acoust Soc Am*, vol. 45, no. 6, pp. 1451–9, 1969.

[3] ——, "Consonance theory part ii: consonance of complex tones and its calculation method," *J Acoust Soc Am*, vol. 45, no. 6, pp. 1460–9, 1969.

[4] R. Parncutt, *Harmony : a psychoacoustical approach*. Berlin ; London: Springer Verlag, 1989.

[5] M. Kastner and R. Crowder, "Perception of the major/minor distinction:iv. emotional connotation in young children," *Music Perception*, vol. 8, no. 2, pp. 189–201, 1990.

[6] T. Brown, S.-i. Tsujimura, A. Allen, J. Wynne, R. Bedford, G. Vickery, A. Vugler, and R. Lucas, "Melanopsin-based brightness discrimination in mice and humans," *Current biology*, vol. 22, no. 12, pp. 1134–1141, 2012.

[7] E. Terhardt, "Pitch, consonance, and harmony," *J Acoust Soc Am*, vol. 55, no. 5, pp. 1061–9, 1974.

[8] H. v. Helmholtz, A. J. Ellis, and H. Margenau, *On the sensations of tone as a physiological basis for the theory of music*, 2nd ed. New York: Dover, 1954.

[9] D. Cook Norman and T. Fujisawa X., "The psychophysics of hermony perception: Harmony is a three-tone phenomenon," *Empirical Musicology Review*, vol. 1, no. 2, pp. 106–126, 2006.

[10] C. Sensory Evaluation, *Sensory Evaluation Handbook*. Tokyo: JUSE Press, Ltd., 1973.

[11] M. Wattenberg, "Arc diagrams: Visualizing structure in strings," p. 110, 2002.

[12] A. Mardirossian and E. Chew, "Visualizing music: Tonal progressions and distributions," in *In 8th International Conference on Music Information Retrieval*, Vienna, 2007, pp. 189–194.

[13] N. Nagata, D. Iwai, M. Tsuda, S. H. Wake, and S. Inokuchi, "Non-verbal mapping between sound and color : Mapping derived from colored hearing possessors and its applications," *The Transactions of the Institute of Electronics, Information and Communication Engineers. A*, vol. 86, no. 11, pp. 1219–1230, 2003.

[14] T. Sangenya, "Non-verbal mapping between sound and color based on chord character evaluation model," Master Thesis, Graduate School of Kwansei Gakuin University, 2010.

[15] N. Nagata, D. Iwai, S. H. Wake, and S. Inokuchi, "Non-verbal mapping between sound and color - mapping derived from colored hearing synesthetes and its applications -," *Proceedings of the 4th international conference on Entertainment Computing*, pp. 401–412, 2005.

978-1-4673-2743-5/12/$31.00 ©2012 IEEE