Complexity Analysis of Instrumental Performance based on Ontology Structure for Music Selection

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Abstract. This paper analyzes the complexity of guitar renditions for learners. We have been developing a domain ontology called the Guitar Rendition Ontology (GRO). GRO structurally describes the actual actions of a classical guitar techniques for sharing information and learning the guitar. These descriptions can be used to provide valid information on music for selecting music. Therefore, we first improved GRO because the several renditions lacked of detailed descriptions. Then, we investigated what types of renditions appear in five existing etude books. After that, we analyzed indicators of the complexity of renditions using the GRO's classes and properties. Furthermore, we attempted to calculate the difficulty of each etude by implementing a novel analysis using TF-IDF and our complexity indicators. Experimental results suggested that the difficulty value of an etude corresponds to the creator's subjectivity and intention.

Keywords: Complexity of Action, Music Selection, Guitar Rendition Ontology

1 Introduction and Background

In playing an instrument, the music selected is an important factor. If players can figure out which techniques they are good or bad at and choose pieces appropriately, they can improve their performance. However, it is not easy to take into account a lot of information, such as the actual sounds and body movements, from information on the music alone. Musical pieces and the order that they are in existing instruction books or etudes are empirically selected by composers or players. There are no quantitative indicators at present. We need to start by defining the difficulty as the difficulty appropriate for each player: what is difficult in the first place and what are the factors. It is possible to more accurately analyze difficulty by defining the complexity of the actual actions of specific guitar techniques.

In our previous study, we developed the Guitar Rendition Ontology (GRO). It can serve as a guideline for playing classical guitar on learning and teaching sites [6]. The ontology consists of 96 concepts that describe the relationships between renditions and 18 properties that explain the features of the concepts. We defined three properties for describing the processes of actions for each rendition as the core structure of the guitar rendition concept, that is, action, primary-action, and conditional-action. The descriptions give information on the appropriate way to perform these actions.

In addition, we focused on guitar renditions used in real performances and investigated the trends and patterns of renditions using GRO [5]. However, the number of renditions alone was not sufficient for accurately determining the difficulty of a performance. To overcome this problem, we attempted to evaluate musical compositions quantitatively by defining the complexity of a rendition on the basis of the ontology structure of GRO. This approach enables a new framework that can support music selection for various instruments. Our goal is to provide indicators for selecting music for classical guitar through an analysis of traditional etude books and a discussion.

The organization of the paper is as follows. In Section 2, we mention related works, and in Section 3, we briefly describe the Guitar Rendition Ontology, discuss the problems with it and how to overcome them, and present a new version of it. In Section 4, we first investigate the characteristics of guitar renditions in existing etude books. Then, in Section 5, we present a detailed method for defining the complexities of guitar renditions and analyze the difficulty of etude pieces. In Section 6, we conclude with a summary and overview of future work.

2 Related Works

There are several approaches related to music selection. One of them is music recommendation, and many systems have been designed by using neural network [4], deep learning [3], emotion recognition [9], and so on. Regarding the classical guitar, [7] analyzed guitar pieces from the perspective of information entropy and provided an indicator to support music selection. The situation we are trying to support in this study is that of an instrumental player selecting a piece of music. We thus need to take into account information related to movement that could represent the difficulty of the actual performance.

The field of knowledge processing, several ontologies related to music have been developed: The Music Ontology (MO) for describing metadata about music in detail [12]; Music Theory Ontology for conceptualizing musical and performance symbols in music notation [13]; Two Ontologies focusing on Feedback in music education [16]; Musical Forms and Structures Ontology (MFSO) and Musical Performance Ontology (MPO), which are developed by extending MO, deals with the musical form and its components, as well as the subjective interpretation and advice (emotion, expression, fingering) of the individual [14]. In addition, MPO defines an ”InstrumentTechnique” class that can handle the movements and fingering necessary to realize musical expression. However, it does not specify the style of rendition and the actions involved, which are the important elements of this paper, nor does it discuss the application of them to music selection. Therefore, we believe that our approach is novel and will contribute to the study of instrumental performance.

3 Improving Guitar Rendition Ontology

In this section, we describe the problems with the present Guitar Rendition Ontology (version 2.4) and how to improve it.

Classes and properties: There are important techniques that are not defined or named as common guitar renditions but are used by many advanced players. One of them is *Curve ceja*, a subclass of *Press string rendition*. In this technique, the index finger arches and presses down on the high and low strings, except for the middle string, in order to play only the necessary strings with minimal force. We thus added the *Curve ceja*. Regarding the *Ornament rendition*, we added the following four ornaments that were missing: *Acciaccatura*, *Appogiatura*, *Double appoggiatura*, and *Schleifer*. In the properties, we added "action4" to describe an action in more detail, and we defined "action" as the upper layer of actions 1 to 4.

Until GRO version 2, we classified several renditions by using numbers such as *Cutting1* and *2*, *Tremolo1* and *2*, and *Tune down1* and *2*. However, these numbers cannot characterize each rendition. Therefore, we gave detailed names to these renditions such as *Cutting with right hand* and *by both hand*, *Tremolo by four fingers* and *by one finger*, and *Tune down with right hand* and *with left hand*.

Description of actions: We modified the action descriptions for about 30 renditions. The problem with the previous version of GRO was that the details of the specifications for some of the actions were not enough. For example, for *Tremolo*, the order of plucking with the right finger is usually p, a, m, and i (initials in Spanish, meaning thumb, ring, middle finger, and index finger), so a description up to "action4" is necessary for each finger. However, the previous version described these four fingers by grouping them together in "action1." To overcome this problem, we tried to break down the actions into smaller pieces and describe them (Figure 1). As *Ornament rendition*s and *Figueta* are also techniques that consist of two or more notes, we improved them to describe the action for each note. However, the explanation of which string is actually plucked is not uniquely determined, and this is a subject for future work.

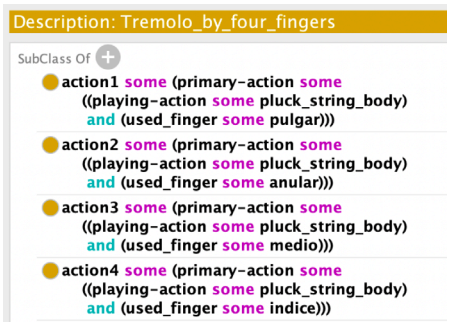

Fig. 1. Description of actions in *Tremolo by four fingers*

Entity / Axiom type	Count
Axiom	1487
Logical axiom	543
Declaration axiom	314
Class	290
-Guitar rendition class	106
Object property	23

Table 1. Ontology metrics of GRO version 3.

Table 1 is a overviews of the improved version[4]. This ontology consists of a total of 313 entities, counting classes, and object properties. The number of classes regarding *Guitar rendition* and the number of properties were increased from version 2.4, from 97 to 106 and from 21 to 23, respectively. Furthermore, axioms that were a combination of

[4] https://github.com/guitar-san/Guitar-Rendition-Ontology

logical, non-logical, and declaration axioms were increased in number by 119 to 1487 by improving the action descriptions in its subclass.

4 Guitar Renditions in Existing Etude Books

This section focuses on learners and investigates what types of renditions appear in existing etude books. There are two cases when making an etude book: (1) books created by the composers themselves and (2) books chosen and organized by performers. Therefore, we tried to identify the differences in renditions when etude books were created from different perspectives.

Since the number of musical pieces varies from book to book, we chose etudes No. 1 to 10 as the subject of our music analysis. We added technique-related information to the musical scores' data and extracted information from MusicXML. Here, one of the authors, who is a guitarist, arranged renditions based on the information already written in the scores.

4.1 Etude books created by composers

The etude books we analyzed are as follows. These were created by two composers from the classical period and a modern composer.

***Estudios Sencillos* by Leo Brouwer:** Leo Brouwer, who was born in Havana in 1939, is a composer, guitarist, conductor, researcher, teacher, and cultural promoter in the modern age. *Estudios Sencillos* [2] is a famous material that has been embraced by many players and by many music schools in their curricula [11].

***25 Etudes Op. 60* by Mauro Carcassi:** Matteo Carcassi (1796-1853) was an Italian guitarist, composer, and pedagogue and is best known for his pedagogical works. His *25 Etudes Op.60* are considered essential works for guitar students. After guitarist Miguel Llobet (1878-1938) added information on fingering, it has been highly regarded as a good teaching tool for learning modern fingering [10].

***12 Etudes Op. 6* by Fernando Sor:** The great Spanish composer and guitarist Fernando Sor (1778-1839) is known for his many guitar compositions. His opus numbers range up to about 63, and these consist of many solo pieces, guitar duets, and songs and guitar pieces. We chose his opus 6, which is known as advanced grade, from several etudes to compare the above books.

Figures 2 to 4 indicate the number of renditions to each etude and the information entropy calculated from them. The etudes of Brouwer and Carcassi have a similar tendency of using *Full planting* in early numbers and *Descending slur* and *Ascending slur* in late numbers. In comparison, the etudes of Sor are structured in such a way that these are used alternately.

Carcassi's etude is often used most on a lesson sites among the above three etudes. The edition by Yasumasa and Seiko Obara, which is often used in Japan, notes that "There are 25 pieces in this collection, and we would like you to follow them in order. The reason is that this is one composition consisting of 25 pieces, all of which are related to each other in key. When you can play all 25 pieces correctly from memory,

you are considered to have achieved a certain level of perfection, hence it is not desirable to practice only one or two pieces" [10]. This suggests that the composer arranged the pieces with the same intention, as the order of the pieces is an important factor in learning the guitar. In fact, Figure 3 demonstrates an increase in both the number of renditions and the information entropy.

In *Estudios Sencillos*, Brouwer stated that "This is the beginning of a series of etudes that were composed for the real guitar apprentice. Every technical problem is separated by the degree of difficulty of the rest of information. If, for instance, there is an arpeggio for the left hand, we are going to do it so that the other hand, in this case the right one, does not find much problem." This suggests that he was as meticulous in composing and structuring his etudes as Carcassi, or even more so. At least, his etudes showed a similar trend to Carcassi's than to Sor's.

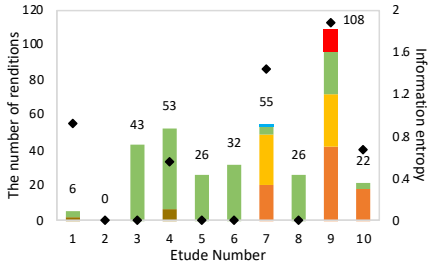

Fig. 2. Change of renditions in *Estudios Sencillos* by Leo Brouwer.

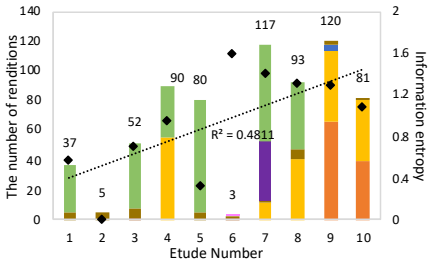

Fig. 3. Change of renditions in etude op. 60 by Matteo Carcassi.

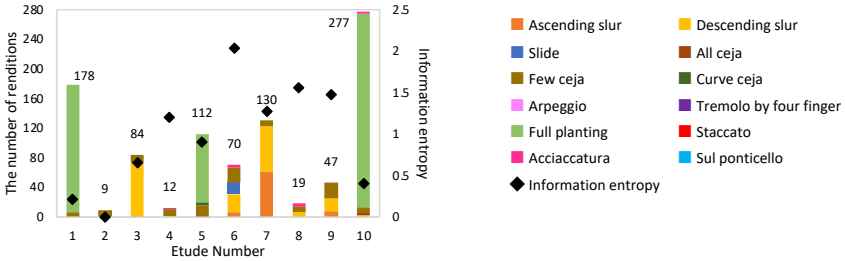

Fig. 4. Change of renditions in etude op. 6 by Fernando Sor.

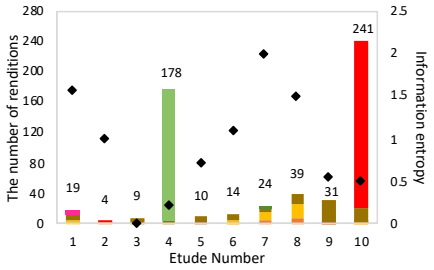

Fig. 5. Change of renditions in Sor's etudes by Andrés Segovia.

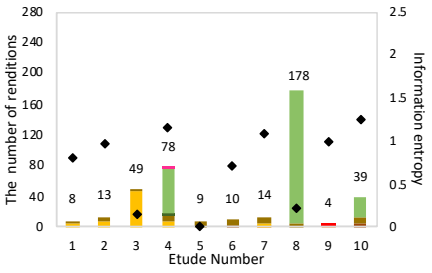

Fig. 6. Change of renditions in Sor's etudes by Yasuo Abe.

4.2 Etude books created by players

We took up Fernando Sor, the composer described in the previous section, and analyzed two etude books collecting his works. These books were published by famous guitarists, and they include pieces other than Op. 6, regardless of the opus number. The data was extracted on the basis of the fingering of each guitarist written in the score.

Twenty Studies by Andrés Segovia: Master musician Andrés Segovia (1893-1987) has selected 20 of Sor's etudes and edited them in a rational order with instructions on fingering, conception, and speed [15].

***25 Etudes* by Yasuo Abe:** This book, which was published by Yasuo Abe (1925-1999), is a collection of Sor's most important etudes for learning all the advanced techniques of the guitar [1].

As shown in Figures 5 and 6, the result differs from Sor's *12 Etudes Op. 6* in that the overall number of renditions is small but that of a few etudes is extremely large. According to Segovia, *Twenty Studies* can be used not only for improving students' technique, but also for maintaining advanced players' technique to a certain level [15]. It includes arpeggio, chords, legato, left hand fingerings, ceja exercises, and many more forms.

Concerning the order of the pieces, Abe noted that "This book is arranged in an easy-to-follow order, which is not the same as Sor's opus numbers," and "Please practice in order from the beginning." This means that the order of the pieces is an important factor in this book. However, it was difficult to identify a specific pattern from these graphs that indicates the above intents. This suggests that, unlike the composer, the players made their selections and ordered the pieces on the basis of their very subjective impressions when playing the pieces.

5 Analyzing Complexity of the Performance

Each guitar rendition requires a different set of actions. The load on the player is different when using a rendition that requires multiple actions or when using a rendition with simple actions. In other words, the complexity of an action relates to the difficulty of the performance. Therefore, we clarified the complexity of each rendition on the basis of the description of actions in the GRO in this section. Here, we analyzed renditions that are located at the bottom of the *Guitar Rendition* Class hierarchy and contain descriptions of actions.

5.1 Complexity of guitar rendition

The calculation rules for weighting properties and classes are as follows.

1. Action Related Properties: Weight of 1 to each of the following properties that represent the relationship of the actions: "action1," "action2," "action3," "action4," "conditional-action1," and "conditional-action2." We excluded "primary-action" and "playing-action" because actions 1–4 contain them.

2. **Detailed Properties:** Some actions have restrictions or requirements in describing the actions in detail such as "direction," "number," "place of action," "part of hand or finger," "timing," "used finger," "used string," "tool," and "ornament tone." We believe that these are related to the complexity of an action. Therefore, the number of properties described in each rendition was additionally weighted.
3. **Player's Action:** It is not only the relationship between actions, but also the type of movement that is important. In the GRO, 22 actions are defined in the class called *Guitar player's action*. We weighted these actions on a scale of 0 to 3. For example, "pluck string" and "touch string" are 0, "press string" and "pick up string" are 1, and "rub string" and "cross strings" are 2. Regarding "use slur," we used the highest value of 3 because *Slur* is defined as a rendition. These values are arbitrary and can be individually adapted to the player.

Figure 7 shows a treemap chart with the complexity value of each rendition represented by the area of the rectangle. The range of values is from a complexity of 1 to 16. *Turn with left hand*, a subclass of the *Ornament rendition*, showed the largest value 16, and other renditions in the same category also tended to map high values. In comparison, the *Fingering rendition* values tended to be low, ranging from the lowest value of 1 for *Al aire* to 8 for *Figueta*, because this is a basic technique of classical guitar. *Percussive rendition* was also similar, with values ranging from 3 to 8. Moreover, all renditions of *Note value rendition* were low at 2.

The values of *Articulation rendition*, *Chord rendition*, *Pitch change rendition*, and *Timbre rendition* varied. The reason for the large difference in values between both *Slur* (also *Slide*) and *Tapping* for the *Articulation rendition* is that the former is a technique learned at the beginning stage, while the latter is an applied technique and uses the attribute "use slur" in GRO. For *Chord rendition*, which requires techniques using multiple strings, *Tremolo* and *Rasgueado* had a large area. *Tremolo* is an especially difficult technique that even some professional guitarists are not good at.

The 12 renditions, extracted in the previous section are represented by black boxes. As mentioned above, *Tremolo* had the largest value because it is a difficult technique. *Ceja* related renditions were large because they required advanced techniques that are performed by pressing multiple strings with a single finger. It is reasonable that the *Descending slur*, which is played by hooking and plucking the string with the left finger, was larger than the *Ascending slur*, which is played just by tapping the string with the left finger. *Descending slur* and *Acciaccatura* are the same action, so the complexity values are equivalent. *Staccato* and *Sul ponticello* were small because they require the simple action of muffling or changing the plucking position with the right finger.

From these results, we found that the complexity indicator corresponds generally to the intuitive difficulty of a rendition. Applying these complexity values to musical pieces can be provided an effective indicator for music selection. However, there is a problem with a few of the rendition values. *Full planting* is a simple technique where the fingers are set before plucking, so the value should be lower than that of *Arpeggio*. We will discuss this further towards a more complete complexity calculation that matches the player's intuition.

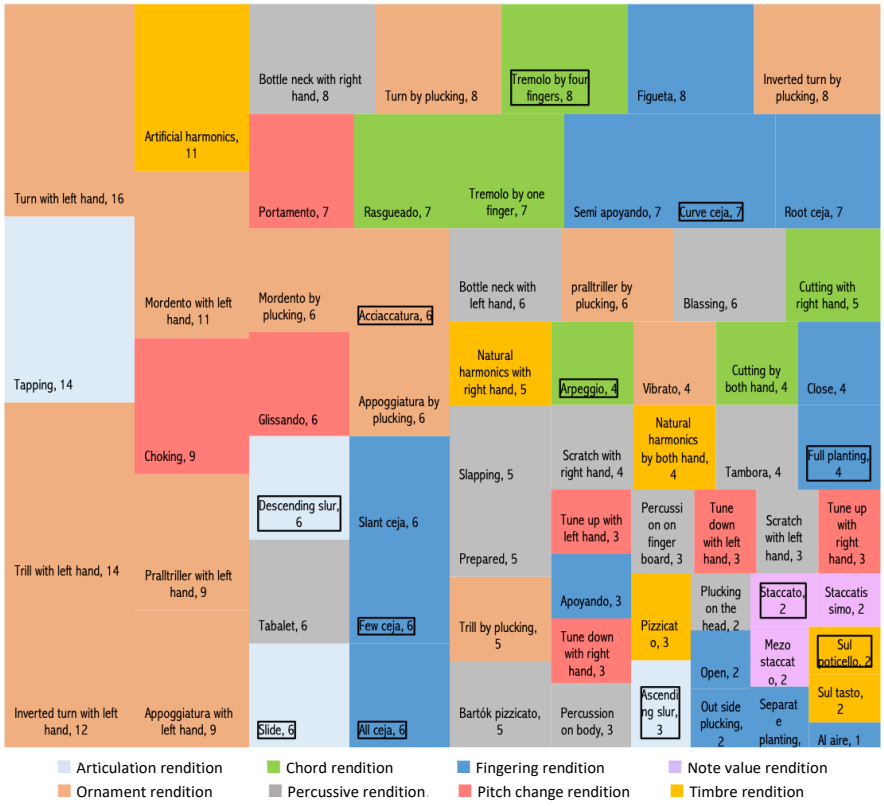

Fig. 7. Treemap of complexity of each guitar rendition.

5.2 Analyzing difficulties of etudes

In regarding to guitar renditions, we think that there are three types of difficulty when playing a musical instrument:

1. Difficulty of the rendition itself
2. Difficulty with the number of renditions
3. Difficulty with the order of the renditions

In this study, we considered the complexity value of a rendition (defined as $complexity_{r,e}$) presented in Section 5.1 as an indicator of type 1. In addition, we attempted to extract indices related to types 2 and 3 by calculating TF-IDF (Term Frequency Inverse Document Frequency) [17] by focusing on the number of occurrences of a rendition. The TF-IDF value is expressed by the following formulas:

$$\text{TF-IDF} = tf_{r,e} \cdot idf_r \qquad tf_{r,e} = \log \frac{n_{r,e}}{\sum_k n_{k,e}} + 1 \qquad idf_r = \log \frac{|D|}{|\{d : t_r \in d\}|} + 1,$$

where $n_{r,e}$ is the value obtained by weighting $complexity_{r,e}$ to the rendition frequency for an etude f_e, $\sum_k n_{k,e}$ is the total number of renditions (including the weight of $complexity_{r,e}$) in the etude, $|D|$ is the total number of etudes in a corpus, and $\{d : t_i \in d\}$ is the number of etudes that contain at least one rendition. Furthermore, the difficulty level of each etude, which is expressed by $difficulty(e)$, is calculated from the following formula:

$$difficulty(e) = \sum_{k \in e} \text{TF-IDF}_{k,e}.$$

Figure 8 indicates the difficulty level of each etude number for the five etude books analyzed in Section 4. Although Carcassi's etude was relatively high and Brouwer's etude was low, both of them had a tendency for the difficulty level to increase: R^2=0.470 and R^2=0.276. Moreover, Abe's etude showed the similar tendency of the line as Carcassi's etude (R^2=0.261). These etudes are popular pedagogical materials around the world. As described in Section 4, it is clear that they took into account the order in which learners can easily practice. For the etude books made by Sor and Segovia, we could not determine whether the difficulty level corresponded to the etude number because the graphs remained almost unchanged. In fact, there are no explicit instructions in those two books regarding the order of the pieces. Therefore, we found that our approach was somewhat consistent with the subjectivity and intentions of the creator (i.e., the author of the etude book). We need to increase the number of analyzed musical pieces and conduct a subjective evaluation of the players using the results obtained in this study.

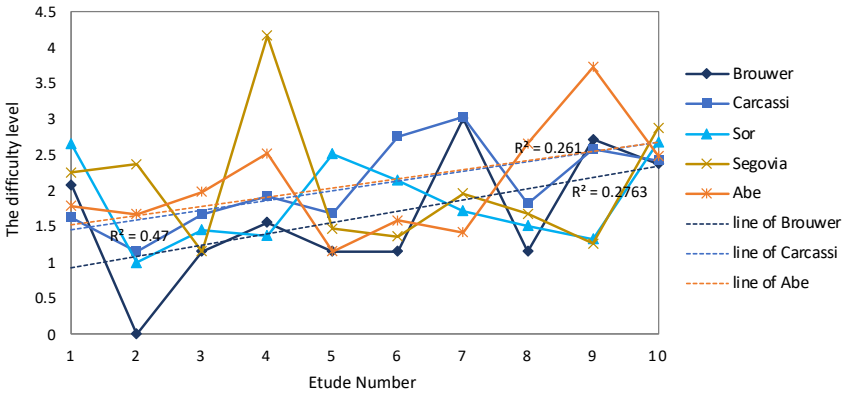

Fig. 8. Difficulties of etudes in five books.

6 Conclusion

In this study, we presented an approach to providing an indicator of the complexity of a guitar rendition and the difficulty of a piece on the basis of the Guitar Rendition Ontology (GRO). We first modified the GRO to describe detailed actions of renditions. Second, we investigated the number of renditions in existing traditional etude books.

Third, we analyzed the renditions' complexities and visualized them with a treemap. Finally, we calculated the difficulty for each etude by using TF-IDF and complexity indicators. As a result, we found that the etude number in etude books corresponded to the subjective perceived difficulty of the creator. The contribution of this paper is to propose a novel approach that quantitatively measures the difficulty of music itself by using a complexity indicator calculated on the basis of the ontology structure of GRO. The advantage of our method is that it is individually adaptable. As a future work, we will construct a framework that will enable music to be selected from more diverse perspectives.

References

1. Abe, Y.: Fernando Sor 25 Etudes, ZEN-ON Music co., Ltd. (1966)
2. Brouwer, L.: Guitar Works for guitar solo, Max Eschig (2006)
3. Fessahaye, F. et al.: T-RECSYS: A Novel Music Recommendation System Using Deep Learning, 2019 IEEE International Conference on Consumer Electronics (ICCE), pp.1–6, (2019)
4. Hansen, C. et al.: Contextual and Sequential User Embeddings for Large-Scale Music Recommendation, In Fourteenth ACM Conference on Recommender Systems (RecSys'20). Association for Computing Machinery, pp.3–62 (2020).
5. Iino, N., Hamanaka, M., Nishimura, T,. K., Takeda H.: Music Analysis with focusing on Techniques by using the Guitar Rendition Ontology, Vol.2019-MUS-124 No.13, (2019)
6. Iino, N., Nishimura, S., Nishimura, T., Fukuda, K., Takeda H.: The Guitar Rendition Ontology for Teaching and Learning Support, The 13th IEEE International Conference on Semantic Computing (ICSC), Resource track, Vol. 1, pp.404–411 (2019)
7. Iino, N., Iizuka, Yasuki., Okino, Shigeki.: Study on Performance Program in Classical Guitar Competitions for Supporting Piece Selection, IPSJ Journal, 59(3), pp.904–911, (2018)
8. Lim, K. A. and Raphael, C.: InTune: a musician's intonation visualization system, ACM SIGGRAPH (2009)
9. Maningo, J.M.Z. et al.: A Smart Space with Music Selection Feature Based on Face and Speech Emotion and Expression Recognition, 2020 IEEE REGION 10 CONFERENCE (TENCON), pp.696–701 (2020)
10. Obara, Y., Obara, S.: 25 Estudios Op.60 Matteo Carcassi, Edition Casa de la Guitarra, No.101 (1965)
11. Penaranda, C., Isaac, C.: Leo Brouwer's Estudios Sencillos for Guitar: Afro-Cuban Elements and Pedagogical Devices, Dissertations, 1002 (2009)
12. Raimond, Y., Abdallah, S.A., and Sandler, M.B., Giasson, F.: The Music Ontology, Proceedings of the 8th International Conference on Music Information Retrieval (2007)
13. Rashid, S.M., Roure, D.D., McGuinness, D.L.: A Music Theory Ontology, Proceedings of the 1st International Workshop on Semantic Applications for Audio and Music, pp.6–14 (2018)
14. Sébastien, V., Sébastien D., Conruyt, N.: Annotating works for music education: propositions for a musical forms and structures ontology and a musical performance ontology, Proceedings of the International Conference on Music Information Retrieval (2013)
15. Segovia, A.: Twenty Studies for the guitar by Fernando Sor, EMI Music Publishing Japan Ltd. (2000)
16. Yee-King, M.J., and Wilmering, T., Rodriguez, M.T.L., and Krivenski, M., d ' Inverno, M.: Technology Enhanced Learning: The Role of Ontologies for Feedback in Music Performance, Frontiers in Digital Humanities, Vol.5, No.29 (2019)
17. Zhang, W., Yoshida, T., Tang, X.: A comparative study of TF*IDF, LSI and multi-words for text classification, Expert Systems with Applications, Vol.38, No.3, pp.2758–2765 (2011).