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Input-Output HMM Applied to Automatic Arrangement for Guitars

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Abstract: Given a relatively small selection of guitar scores for a large population of guitarists, there should be a certain demand for systems that can automatically arrange an arbitrary score for guitars. Our aim in this paper is to formulate the "fingering decision" and "arrangement" in a unified framework that can be cast as a decoding problem of a hidden Markov model (HMM). The left hand forms on the fingerboard are considered as the hidden states and the note sequence of a given score as an observed sequence generated by the HMM. Finding the most likely sequence of the hidden states thus corresponds to performing fingering decision or arrangement. The manual setting of HMM parameters reflecting preference of beginner guitarists lets the framework generate natural fingerings and arrangements suitable for beginners. Some examples of fingering and arrangement produced by the proposed method are presented.

Keywords: guitar, fingering decision, arrangement, hidden Markov model, Viterbi algorithm

1. Introduction

The pitch ranges of the guitar strings have significant overlaps so that string and fret to depress cannot be determined uniquely even for playing a single note. A consequence is that several fingerings are possible for a single passage and it is difficult for beginner guitarists to determine a fingering for playing the passage. This is why guitar scores for beginner guitarists are usually attached with tablatures which are musical notations that indicate instrument fingerings rather than musical notes. Given a guitar score without tablature or a score for any other instrument than the guitar, a guitarist has to carry out "fingering decision" or "arrangement" by oneself before playing it with the guitar. "Fingering decision" is a process of determining which finger should be placed on which string and fret for each note, given a guitar score without tablature. "Arrangement," on the other hand, is a process of finding a reasonable fingering for a given score which is not playable by the guitar owing to the limitations of the pitch range or the number of voices (simultaneous notes). It makes as few modifications as possible to the given score to make it playable by the guitar and then determines a fingering for the modified version of the score. Given a relatively small selection of guitar scores for a large population of guitarists, there should be a certain demand for systems that performs fingering decision and arrangement automatically.

Our aim in this paper is to formulate fingering decision and arrangement in a unified framework that can be cast as a decoding problem of a hidden Markov model (HMM) based on previous developments [12], [13]. As for the fingering decision, that is a subproblem of arrangement, several works have been made in the last two decades. Sayegh [2] introduced "optimum path paradigm" to fingering decision of generic string instruments. Miura et al. [7] developed software that generates guitar fingerings for given melodies (sequences of single notes). Radicioni et al. [5] extended Sayegh's approach paying attention to cognitive aspects underlying the fingering decision. Radisavljevic and Driessen [6] proposed a method for designing cost functions required in dynamic programming (DP) for fingering decision. Tuohy and Potter [8] introduced a genetic algorithm (GA) for fingering decision and Tuohy [9] extended their approach to arrangement for guitars. Baccherini et al. [11] introduced finite state automaton to fingering decision of generic string instruments. The novelty of the present work, in comparison with those previous ones, mainly lies in that it is based on a stochastic model. The relation between a sequence of notes and a fingering is modeled based on HMM which is a stochastic model expanding its application field to music information processing. We are able to address fingering decision and arrangement in a unified way by virtue of the flexibility of HMM, and perform those processes with reasonable computation time even for polyphonic pieces as the Viterbi algorithm can solve the decoding problem of HMM very efficiently.

The remainder of the paper is organized as follows. Section 2 introduces a framework based on HMM for fingering decision which is a subproblem of arrangement. Section 3 extends the framework to automatic arrangement by adding output symbols to the HMM for fingering decision. Section 4 sets the HMM parameters such as the state transition and output probabilities so that the HMM performs fingering decision and arrangement. Section 5 concludes the paper and discusses related future works.

Throughout the paper, we suppose a guitar with six strings and 19 frets in the standard tuning [*1].

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*1 E2-A2-D3-G3-B3-E4

2. Fingering Decision Using HMM

We start with applying HMM to fingering decision which is a subproblem of arrangement. In the case where a given piece is playable by the guitar, a problem of arrangement for guitars reduces to a problem of fingering decision.

2.1 Guitar Fingering

A guitarist plays musical notes with the guitar by depressing strings on the fingerboard with the left hand and picking strings with the right hand. In the present study, we use the term "form" to refer to the placement of the left hand fingers on the fingerboard as well as the choice of strings to pick with the right hand to play a single chord. A piece of music is a sequence of notes while a "fingering" is a sequence of such forms that plays a piece of music. A guitar performance is a process in which a piece of music (a sequence of notes) is generated from a fingering (a sequence of forms). Conversely, given a piece of music, "fingering decision" is the process of finding a fingering that plays the given piece of music.

The pitch ranges of the guitar strings have significant overlaps, thus string and fret to depress cannot be determined uniquely even for playing a single note. A consequence is that we have several fingerings for a single sequence of notes and various factors influence the choice of fingerings. Our aim in this paper is to introduce a framework that formulates fingering decision and arrangement in a unified way as a problem of finding the most probable sequence of forms, given a sequence of notes. Within this framework, various factors that influence the choice of fingerings are represented by the state transition and output probabilities.

2.2 HMM for Fingering Decision

If we assume that the choice of the left hand form depends only on the previous form, a guitar performance can be described using a hidden Markov model (HMM) in **Fig. 1** where the hidden states are the left hand forms and the output symbols are the chords that are played by the forms. Consequently, each hidden state outputs a unique output symbol while it is possible that several hidden states output the same output symbol. In this framework, the given sequence of notes is considered to be generated from a hidden sequence of forms (a fingering). Even if the fingering cannot be determined uniquely from the given sequence of notes, the most probable fingering can be determined based on maximum likelihood estimation. The problem of finding the most probable sequence of hidden states is called the "decoding problem" and can be solved efficiently using the Viterbi algorithm [1].

To perform fingering decision using the above-mentioned framework, we consider the case with the following restriction. That is, we concentrate on guitar pieces in which all the notes that start together stop together. Although there are guitar pieces in which some of the notes that start together stop or change to different notes while others continue, we leave such cases out of consideration to perform fingering decision using the framework based on HMM. Even if a given piece does not meet this condition, it can be modified by shortening longer notes to meet the condition. Because tone of the guitar does not sustain like that of the organ, such modification does not significantly change the impression of guitar pieces. To summarize, we consider a guitar piece as a "sequence of chords" where a chord is a set of notes that start and stop together.

In reality, the choice of the left hand form depends not only on the previous form but also on the time interval between the current chord and the previous chord. When the time interval is very long, we can almost ignore the dependency on the previous form, that is, the time interval inhibits the dependency. To take into account such effect of time intervals, we employ "input-output HMM" introduced by Bengio and Frasconi [3], an extension of standard HMM. A graphical model representation [10] of the input-output HMM we employ for fingering decision and arrangement is given in **Fig. 2** where the shaded nodes are observed variables while the white ones are latent variables and the arrows connecting nodes denote the conditional dependencies of the variables. The input-output HMM has the sequence of observed variable d_t, in addition to the sequence of output variable x_t, that influences the distribution of the latent variable z_t. The observed variables x_t and d_t denote the t-th chord of a given piece

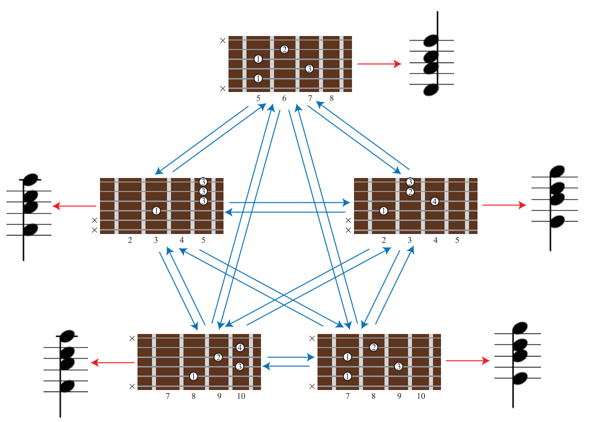

Fig. 1 HMM for fingering decision: The hidden states are the forms of the left hand and the output symbols are the chords that are played by the forms. Consequently, each hidden state outputs a unique output symbol while it is possible that several hidden states output the same output symbol.

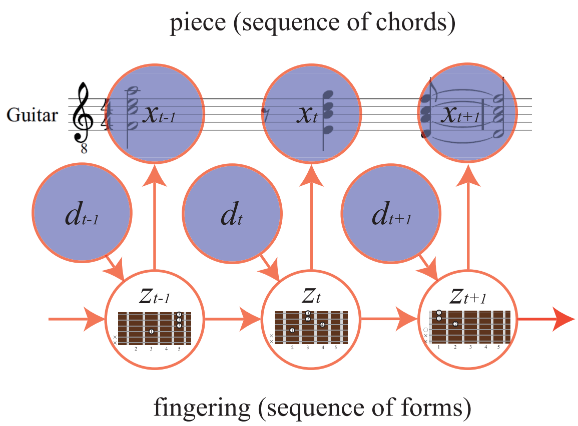

Fig. 2 Graphical model representation of input-output HMM for fingering decision and arrangement: In the diagram, x_t, d_t and z_t denote chords, time intervals between chords, and forms respectively. The shaded nodes (chords and time intervals) are observed variables while the white ones (forms) are latent variables. The arrows connecting nodes denote the conditional dependencies of the variables.

and the time interval between two chords x_{t-1} and x_t. The latent variable z_t denotes a form of the left hand which is represented by one of N possible values $q_1, q_2, \ldots, q_N$. The decoding problem of the input-output HMM described in Fig. 2 can be solved efficiently using the Viterbi algorithm in the same way as standard HMM.

3. Automatic Arrangement Using HMM

We move on to automatic arrangement for guitars using HMM. We employ the same input-output HMM for fingering decision with additional output symbols. We mainly suppose piano pieces as targets of automatic arrangement.

3.1 Arrangement for Guitars

In the present study, "arrangement for guitars" means making minimum modifications to a given piece to make it playable by the guitar [*2]. Although the term "arrangement" is also used to mean making modifications to an existing piece to alter the impression intentionally, we use the term in the former sense.

To perform arrangement for guitars using the framework based on HMM, we again concentrate on pieces in which all the notes that start together stop together. Simply put, a given piece to arrange is assumed to be a "sequence of chords." Even if a given piece to arrange does not meet this condition, it can be modified by shortening longer notes to meet the condition before arrangement.

To make a given piece playable by the guitar, we need to modify chords in the given piece if they are not playable by the guitar due to the limitations of the pitch range or the number of voices (simultaneous notes). First, the pitch range of the guitar is E2–B5 and chords including notes outside the range must be modified so that they include only notes inside the range. Second, the maximum number of voices is six (the number of the strings) for the guitar and therefore chords including more than six notes must be modified so that they include up to six notes. Moreover, some chords cannot be depressed with four fingers of the left hand although they meet the limitations of the pitch range and the number of voices. Also, such chords must be modified so that they can be depressed with four fingers.

Such unplayable chords beyond the pitch range or the maximum number of voices can be modified to playable ones by omitting notes. When we omit notes of unplayable chords, we have to pay attention to the top and bottom notes that play important roles to create the impression of the piece. First, the top notes of chords basically form the melody line of the piece and cannot be omitted [*3]. Second, the bottom notes of chords are the "roots" and should not be omitted if possible. If a bottom note is below the pitch range of the guitar, it is better to move it up an octave. In our formulation of arrangement for guitars, we modify unplayable chords of a given piece using the following two operations:

(1) to omit a note, and

(2) to change octaves of a note.

We use the operation (2) only when the changed note does not exceed the top note of the chord. If the changed note overlaps with an existing note, then the changed note is omitted.

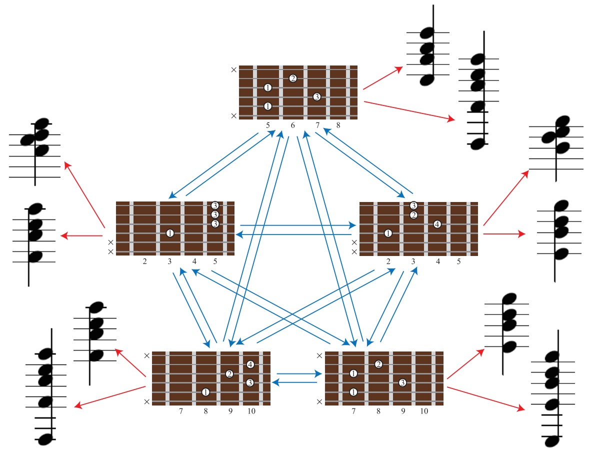

Fig. 3 HMM for automatic arrangement: We employ basically the same input-output HMM for fingering decision except that each hidden state has additional output symbols, that is, each form outputs the chord played by the form as well as those with a few modifications. Consequently, the HMM for automatic arrangement can output a piece unplayable by the guitar.

3.2 HMM for Automatic Arrangement

Automatic arrangement can be performed using basically the same input-output HMM employed for fingering decision by adding output symbols as explained in the following. In the HMM for fingering decision in Fig. 1, each form outputs the chord played by the form. This guarantees that the most probable sequence of forms is a fingering that plays the given piece. On the other hand, in the HMM for automatic arrangement in **Fig. 3**, each form outputs also the chords that can be modified to the chord played by the form using the operations (1) and (2) explained in the previous section. This qualifies the most probable sequence of forms as a fingering that plays a sequence of chords similar to the given piece.

4. Manual Setting of HMM Parameters

HMM parameters such as the state transition and output probabilities are usually estimated from training data using the EM algorithm in standard applications of HMM including speech and handwriting recognition. The HMM employed in the present study, however, has a huge number of hidden states, thus making it difficult to prepare enough training data to learn those HMM parameters. Instead, we set those parameters manually as explained in the following. We suppose that main users of the present system are beginner guitarists who would prefer to minimize the movement of the left hand along the neck and avoid difficult forms of the left hand.

4.1 State Transition Probability

First, to minimize the movement of the left hand along the neck, the state transition probability needs to be a monotone decreasing function of the movement with the transition. In addition, typically, guitarist's left hand position is not moving all the

[*2] The term "transcription" is also used for this meaning.

[*3] If any chord includes a note above the pitch range of the guitar, we have no other choice than to transpose the piece down. We leave such "arrangement with transposition" to our future study.

time but is staying at a position for several notes and leaps a few frets to a new position. A consequence is that the distribution of a single step of the movement is sparse and concentrates on the center. We employ the Laplace distribution to approximate such a sparse distribution concentrated on the center. The time evolution of a Markov process with Laplace-distributed increments is known to be closely approximated by a piecewise constant function [*4] that resembles the movement of guitarist's left hand along the neck. Furthermore, as previously mentioned, the choice of the left hand form depends not only on the previous form but also on the time interval between the current chord and the previous chord. When the time interval is very long, we can almost ignore the dependency on the previous form, that is, the time interval inhibits the dependency. To take into account such effect of time intervals, we let the variance of the Laplace distribution be proportional to the time interval d_t so that the distribution approaches the uniform distribution as the time interval d_t approaches infinity.

Secondly, to avoid difficult forms of the left hand, the state transition probability needs to be a monotone decreasing function of the "difficulty" of the destination form. We pick up three difficulty levels of the form q_i, that is, the index finger position I_i, the width W_i and the number of working fingers N_i, and reflect them independently to the state transition probability. The number of working fingers N_i is obviously one of the difficulty levels of the form q_i. The index finger position I_i is also a difficulty level of the form q_i because a parallel translation to a higher position makes playing a chord more difficult. The index finger position I_i and the width W_i of the form q_i are explained in detail in the following paragraph. The discussion so far leads us to set the probability of the state transition from the form q_i to the form q_j given the time interval d_t as

$$\begin{aligned} a_{ij}(d_t) &= p(z_t = q_j \mid z_{t-1} = q_i,\ d_t) \\ &\sim \frac{1}{2d_t} \exp\left(-\frac{|I_i - I_j|}{d_t}\right) \\ &\quad \times \frac{1}{1+I_j} \times \frac{1}{1+W_j} \times \frac{1}{1+N_j} \end{aligned}$$

where the first term of the right hand side is the density function of the Laplace distribution with the variance d_t and $|I_i - I_j|$ represents the movement of the left hand along the neck with the transition.

Figure 4 gives three examples of forms and their index finger positions, widths, and numbers of working fingers, where the numbers 1–4 in the circles on the fingerboard stand for the index, middle, ring and little fingers respectively. The index finger position I_i is defined to be the number of the fret the index finger depresses. For a form in which the index finger does not depress, we consider that idling fingers are on consecutive frets with working fingers and define the index finger position I_i to be the number of the fret the index finger is on. In the top and middle figures in Fig. 4, the index finger depresses the second and fifth fret and then the index finger position is defined as $I_i = 2$ and $I_i = 5$ respectively. In the bottom figure, only the ring finger depresses and all the other fingers are considered to be on consecutive frets

*4 See Ref. [4], p.315, for example.

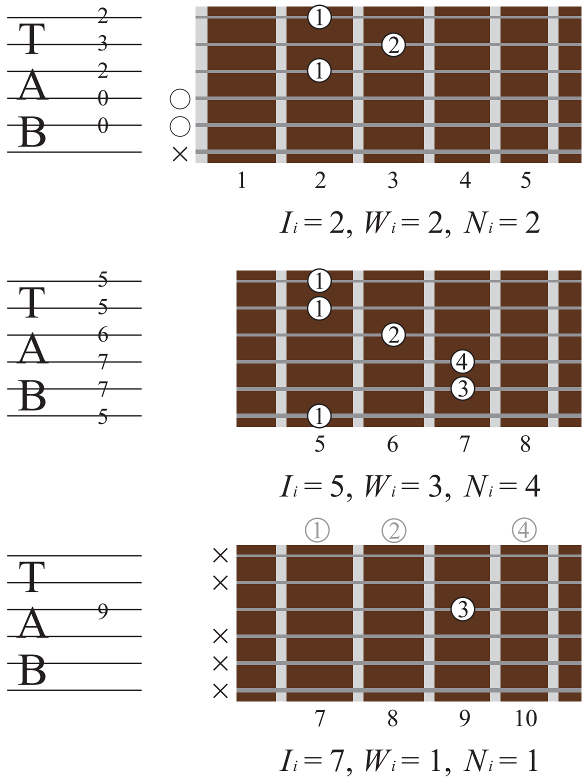

Fig. 4 Three forms of the left hand and their index finger positions I_i, widths W_i and numbers of working fingers N_i: The index finger position I_i is defined to be the number of the fret the index finger depresses or is on. The width W_i is the dimension of the form along the neck. The number of working fingers N_i is defined to be the number of fingers that depress in the form.

where the index finger is on the seventh fret and then the index finger position is defined as $I_i = 7$. The width W_i of a form is its dimension along the neck and is defined as

$$W_i = F_i^{\max} - F_i^{\min} + 1$$

where $F_i^{\max}$ and $F_i^{\min}$ denote the maximum and minimum numbers of frets depressed in the form respectively. For a form that consists of only open strings, its width is defined as $W_i = 0$. The width is considered as one of difficulty levels of a form because it is difficult to give enough pressure to all the working fingers in a form spreading over many frets. The number of working fingers N_i is defined to be the number of fingers that depress in the form. Figure 4 also gives the widths and the numbers of working fingers of the three examples of forms.

4.2 Output Probability for Fingering Decision

For the input-output HMM to solve fingering decision as a decoding problem, we set the output probability b_{it} to zero if the chord played by the form q_i does not coincide with the t-th chord x_t of a given piece. Otherwise we set the output probability b_{it} to one. That is, we set the output probability of the chord x_t from the form q_i as

$$\begin{aligned} b_{it} &= p(x_t \mid z_t = q_i) \\ &\sim \begin{cases} 1 & (\text{if } x_t = \mathit{chord}(q_i)) \\ 0 & (\text{if } x_t \neq \mathit{chord}(q_i)) \end{cases} \end{aligned}$$

where $\mathit{chord}(q_i)$ denotes the chord played by the form q_i. This setting of the output probability implements the HMM in Fig. 1 and guarantees that the most probable sequence of forms is a fingering that plays the given piece.

4.3 Output Probability for Arrangement

For automatic arrangement, we set the output probability b_{it} to zero if the t-th chord x_t of a given piece cannot be modified to the chord played by the form q_i using the operations (1) and (2) explained in Section 3.1. Otherwise we set the output probability b_{it} to a positive value. This setting of the output probability implements the HMM in Fig. 3 and makes the most probable sequence of forms qualified as a fingering that plays a sequence of chords similar to the given piece. Furthermore, to choose chords with the minimum modifications, the output probability b_{it} needs to be a monotone decreasing function of the number of the operations required to modify the t-th chord x_t of a given piece to the chord played by the form q_i. For this purpose, we set the output probability of the chord x_t from the form q_i as

$$b_{it} = p(x_t \mid z_t = q_i) \sim \begin{cases} \dfrac{1}{1+M_{it}} & (\text{if } x_t \Rightarrow \mathit{chord}(q_i)) \\ 0 & (\text{if } x_t \not\Rightarrow \mathit{chord}(q_i)) \end{cases}$$

where M_{it} denotes the number of operations (1) and (2) required to modify the chord x_t to the chord played by the form q_i and we write $x_t \Rightarrow \mathit{chord}(q_i)$ when the chord x_t can be modified to the chord played by the form q_i using the operations.

5. Evaluation and Comparison

We conducted experiments to evaluate the proposed fingering decision and automatic arrangement based on input-output HMM. First, we evaluated fingering decision using two major scales and a polyphonic guitar piece. The results were compared to those of two existing programs. Next, we evaluated automatic arrangement using a piano piece that is not playable by the guitar.

5.1 Fingering Decision

We performed the proposed fingering decision based on input-output HMM and then compared the results to those of two existing programs, that is, Power Tab Editor [*5] (Ver.1.7) and Guitar Pro [*6] (Ver.6). Power Tab Editor is a free tablature editor and has a large user community on the Internet. Power Tab Editor's file format is a standard in exchanging guitar tablatures. On the other hand, Guitar Pro is a commercial tablature editor that covers ukulele, banjo and eight-string guitar. Specifically, we performed the proposed fingering decision for a one-octave major scale from C4 to C5, an extended major scale from C4 to D5, and the opening section of a guitar version of "Joy to the world." For the sake of comparison, we input the same sequences to Power Tab Editor to generate a fingering, and then input the result to Guitar Pro and applied the "Automatic finger positioning" command of Guitar Pro to obtain an improved fingering.

Figure 5 presents the results of fingering decision for a one-

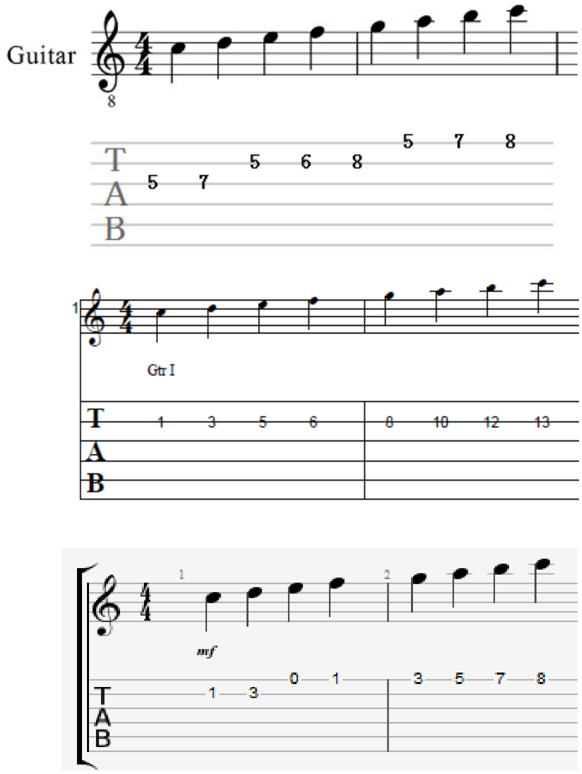

Fig. 5 The fingerings for a one-octave major scale from C4 to C5 generated by the proposed method (top), Power Tab Editor (middle) and Guitar Pro (bottom): The fingering of the top figure fixes the index finger to the fifth fret to minimize the movement of the left hand. The fingering of the middle figure uses only the second string throughout the scale to force players to move their left hand along the neck. The fingering of the bottom figure utilizes two strings but still forces players to move their left hand.

octave major scale from C4 to C5. The top figure presents the fingering generated by the proposed method based on input-output HMM. The fingering fixes the index finger to the fifth fret to minimize the movement of the left hand and is one of natural fingerings human guitarists would choose when they play a one-octave major scale. The movement of the left hand is minimized by virtue of the manually-set state transition probability. The middle figure presents the fingering generated by Power Tab Editor. The fingering uses only the second string throughout the scale and forces players to move their left hand along the neck. Although we cannot conclude that the fingering is nonsense because expert guitarists could choose it in some specific situation, it is obvious that it is not for beginner guitarists. The bottom figure presents the fingering generated by Guitar Pro that utilizes two strings but still forces players to move their left hand along the neck. Obviously, the fingering generated by input-output HMM minimizes the movement of the left hand among those three fingerings.

Figure 6 presents the results of fingering decision for an extended major scale from C4 to D5. We performed this experiment to see how the proposed method responds to the last note appended to the one-octave major scale in Fig. 5. The top figure presents the fingering generated by the proposed method based on input-output HMM. Compared to Fig. 5, we note that the appended note changes the whole fingering. This is because the Viterbi algorithm performs "path optimization." Even the fingering for the first note is changed through the optimization of the

*5 http://www.power-tab.net
*6 http://www.guitar-pro.com

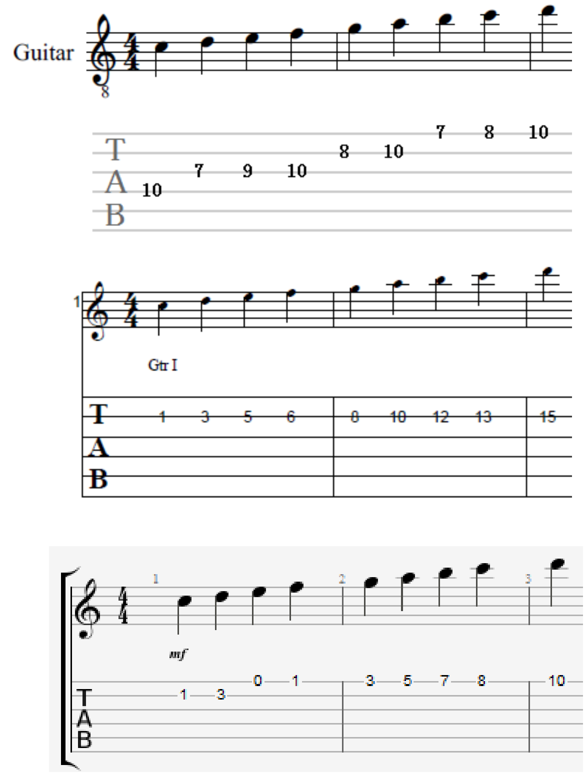

Fig. 6 The fingerings for an extended major scale from C4 to D5 generated by the proposed method (top), Power Tab Editor (middle) and Guitar Pro (bottom): In the top figure, compared to that of Fig. 5, appending a single note changes the whole fingering to minimize the movement of the left hand by fixing the index finger to the seventh fret. In the middle and bottom figure, the appended note is simply assigned to the same string as previous notes to increase the movement of the left hand.

whole fingering. The resulting fingering fixes the index finger to the seventh fret to minimize the movement of the left hand. The middle and bottom figures present the fingerings generated by Power Tab Editor and Guitar Pro respectively. Compared to Fig. 5, we note that the fingerings for the first eight notes are not changed and the appended notes are simply assigned to the same strings as previous notes. Such an intelligent response as the proposed method took was not observed in the middle and bottom figures.

Figure 7 presents the results of fingering decision for a guitar version of "Joy to the world." The top figure presents the fingering generated by the proposed method based on input-output HMM. The proposed method generated a fairly realistic fingering even for a polyphonic guitar piece. The generated fingering chooses forms with small widths, utilizes open strings and minimizes the number of working fingers by virtue of the manually-set state transition probability. The middle figure presents the fingering generated by Power Tab Editor. Compared to the top figure, the number of open strings are decreased and the widths of forms are increased. The bottom figure presents the fingering generated by Guitar Pro. Also the number of open strings are decreased and the widths of forms are increased compared to the top figure. The form for the second chord in the bottom figure is very difficult to play.

Fig. 7 The fingerings for the opening section of "Joy to the world" generated by the proposed method (top), Power Tab Editor (middle) and Guitar Pro (bottom): The fingering in the top figure chooses forms with small widths, utilizes open strings and minimizes the number of working fingers. Compared to the top figure, the middle and bottom figures utilize less open strings and choose forms with larger widths to make fingerings relatively difficult. The bottom figure chooses a very difficult form for the second chord.

Fig. 8 An excerpt from Frédéric Chopin's "Fantasie in F minor, Op. 49" composed for the piano (top), the resulting arrangement for guitars (middle) and guitar tablature (bottom): The notes with red diagonal lines are omitted while the ones with red squares go up an octave in the resulting arrangement which is playable by the guitar.

5.2 Automatic Arrangement

Figure 8 presents the result of automatic arrangement for an excerpt from Frédéric Chopin's "Fantasie in F minor, Op. 49" where the piano score (top) was given as an observation sequence and the guitar tablature (bottom) was obtained by the Viterbi algorithm as the most probable sequence of hidden states. The given piano score is not playable by the guitar because it includes notes outside the pitch range of the guitar (indicated with red squares) and notes that cannot be depressed with four fingers (indicated with red diagonal lines). Such notes were modified through automatic arrangement. The notes with red diagonal lines are omitted while the ones with red squares go up an octave in the resulting arrangement. Among the notes with red squares, the second and third ones go up to overlap with existing notes and then they are omitted. After modifications explained above, we obtained an arrangement which is playable by the guitar. From the result, we see that automatic arrangement can be performed using the same input-output HMM for fingering decision with additional output symbols.

6. Concluding Remarks

Fingering decision and arrangement have been formulated in a unified framework that is cast as a decoding problem of HMM in which the hidden states are the left hand forms and an observed sequence is a given sequence of notes. In the HMM for fingering decision, the output symbols are the chords that are played by the forms. We have set the state transition probability based on the movement of the left hand and the difficulty levels of the destination form, and then successfully obtained one of natural fingerings human guitarists would choose. In the HMM for automatic arrangement, each form outputs the chord played by the form as well as those with a few modifications. Accordingly, we have changed the output probability based on the number of modifications and then obtained an arrangement playable by the guitar which is close to a given piece. The proposed framework also offers other capabilities than fingering decision and automatic arrangement. First, the HMM for fingering decision can be used to judge whether or not a given piece is playable by the guitar. Secondly, the probability of obtained fingering (the most probable sequence of forms) can be used as a difficulty level of a given piece.

A web application is currently under development for implementation of the framework introduced in the paper and will be made public soon. Users of the system are able to open a standard MIDI file (SMF) and carry out fingering decision and arrangement with a graphical user interface using standard web browsers. The web application will be used for subjective assessment with guitarists of the robustness and the limitations of the proposed method.

As stated in Section 3.1, if any chord of a given piece to arrange includes a note above the pitch range of the guitar, we have no other choice than to transpose the piece down. We leave to our future study such “arrangement with transposition” that performs arrangement as well as finds the optimal transposition for playing the piece with the guitar. It can be carried out by a full search for all the possible keys, if we can design an appropriate cost function that evaluates generated tablatures. Also our future study will challenge to adapt our proposed framework to a variety of guitars and guitarists by flexible settings of HMM parameters. Although we have supposed beginner guitarists as prospective users of our proposed system in the setting of HMM parameters, ideal fingerings and arrangements actually depend on types of guitarists (such as beginners and experts) as well as types of guitars (such as classical guitars and electric guitars). We will challenge to model such dependency on types of guitarists and guitars in HMM parameters. Finally, the results presented in the paper encourages us to develop similar kinds of fingering decision and arrangement systems based on HMM for other instruments.

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