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Method for estimating proficiency in playing acoustic piano

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ABSTRACT

Today, more and more people want to play the piano but have limited time and financial resources, which means that many cannot learn from professionals. Therefore, support systems for self-learners have been developed. However, these studies were only for the MIDI piano, and the acoustic piano is difficult to use with previous systems. We propose a method of converting an acoustical signal of a piano into a MIDI signal. Our method is used to estimate the onset time, MIDI velocity, and duration for each note from the acoustical signal, resulting in an estimation system for proficiency. Usually the acoustic power of the piano has many peaks, the highest points are difficult to estimate by computer, so estimating onset time using only time information is difficult. Therefore, our method uses information on both time and frequency to estimate an onset time. For information on frequency, the method has a judging function with a correlation coefficient between consecutive pitch class profiles (PCPs), which PCP are pitches with ignoring the difference in octave. We expect the correlation coefficient using PCPs to be able to detect the onset time in accordance with the change in sounding pitches on piano keys that are consecutively played. For information on time, the method calculates the envelope of the waveform. After it has calculated a moving average for the obtained envelope, it estimates its peak time, i.e., the onset time when the value of a PCP function is judged to be high, near the peak on the moving average. For estimating MIDI-velocity, the proposed method estimates the height of the peak point of the waveform around the estimated onset time. The peak height of a point of the waveform is compared with the acoustic power that corresponds to the MIDI-velocity of the recorded MIDI signal. To determine the MIDI-velocity of the input sound, the nearest value is selected. For estimating the duration, the time when the power of PCP attenuates is regarded as the offset time. The interval by subtracting the onset time from the offset time is regarded as the duration. An experiment in which scales were played and recorded shows that our method shows goog results. Concretely speaking, proficiency scores produced using the proposed method are compared with those given by expert pianist. These proficiency scores are strongly correlated (r=.58(n=336)), confirming the effectiveness of our method.

1. INTRODUCTION

The number of people who want to acquire piano skills has been increasing; therefore, there are now many self-learners. However, some learners cannot learn from professionals because of time and economic constraints. Also, self-learners cannot acquire an objective evaluation or practice their skills effectively. Therefore, several support systems for self-learners of piano have been developed [1-3]. However, these studies are for only MIDI systems, so the acoustic piano is difficult to use with previous support systems. We propose a method for converting an acoustical signal of a piano into a MIDI signal in order to use our previously proposed MIDI-based support system with acoustic pianos. The proposed method estimates the onset time, duration, and MIDI velocity for each note from an acoustical signal and converts them to MIDI notes, resulting in an estimation of proficiency using the MIDI notes. Finally, we developed a support system for practice of playing an acoustic piano. Section 2 outlines our proposed method for estimating proficiency, Section 3 describes our proposed method of estimating onset time based on time and frequency information, Section 4 describes our proposed method of estimating duration based on the acoustic power of chroma, Section 5 describes our proposed method of estimating MIDI velocity based on acoustic power, and Section 6 describes a performance experiment and results. Finally, Section 7 gives conclusions and future work.

2. OUTLINE OF PROPOSED SYSTEM

The proposed method estimates the onset time, duration and MIDI velocity for each musical note from an acoustical signal. Moreover, it estimates proficiency based on a method proposed in a previous study [4]. The flow of a support system based on our proposed method is shown in Fig. 1, and the display output of the proposed system is shown in Fig. 2. The performance task used in this study was the playing of a scale within one octave on a piano. The musical score used is shown in Fig. 3.

3. ONSET ESTIMATION

3.1. Outline of onset estimation

In general, the acoustic power of a piano has many peaks, making the highest points difficult to determine. In other words, it is difficult to estimate the onset time based on only the time information of the acoustic waveform. The proposed method uses time and frequency information for estimating the onset time. For time information, the proposed method uses the acoustic power of the waveform, where it obtains a moving average for the envelope obtained by half-rectification. For frequency information, the proposed method uses a judging function with a correlation coefficient between consecutive pitch-class profiles (PCPs), which are pitches with blind respect to the difference in octave [5]. It is assumed that the correlation coefficient of PCPs represents the change in sounding pitches on piano keys pressed consecutively. Finally, the proposed method obtains the onset time when the value of a PCP function is highest around the peak time of the moving average, is judged to be the onset time. The outline of onset time estimation is shown in Fig. 4.

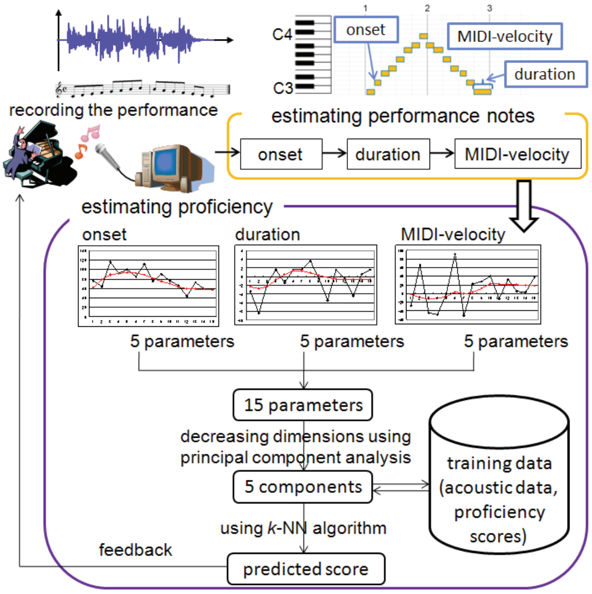

Figure 1. Flow of proposed system

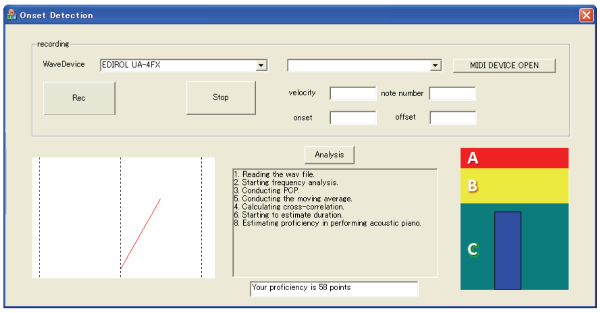

Figure 2. Display output of support system

Figure 3. Musical score for scale performance used in this study

3.2. Estimation using time information

For time information, the proposed method uses the acoustic power of the waveform. However, acoustic power generally has many peaks, so it is difficult to correctly determine the highest point. Therefore, it is difficult to estimate the onset time using only time information. The proposed method conducts a moving average for the obtained envelope, so that peak time of the waveform is easily estimated from the curve of the moving average. After the proposed method calculates half-wave rectification, it obtains the moving average curve $\overline{x}_M(t)$, shown in the average in the range of $\pm M/2$ around t, where M=90 ms. The proposed method regards the location, where a value of $\overline{x}_M(t)$ suddenly increases, as the peak times on $\overline{x}_M(t)$, where the proposed method uses the peak times to estimate the onset time. Specifically, the method calculates an average of $\overline{x}_M(t)$ as "Average($\overline{x}_M(t)$)". Next, it calculates the differential of $\overline{x}_M(t)$, denoted as $\overline{x}_M'(t)$. When the $\overline{x}_M'(t)$ values are higher than a threshold value and $\overline{x}_M(t)$ values are more than Average($\overline{x}_M(t)$), the times are regarded as the peak time of $\overline{x}_M(t)$, represented as t_{peak}. After t_{peak} is obtained, the next peak of the subsequent note is then estimated with the point at 50 ms. Extracted t_{peak} are used to determine the onset by using the frequency information.

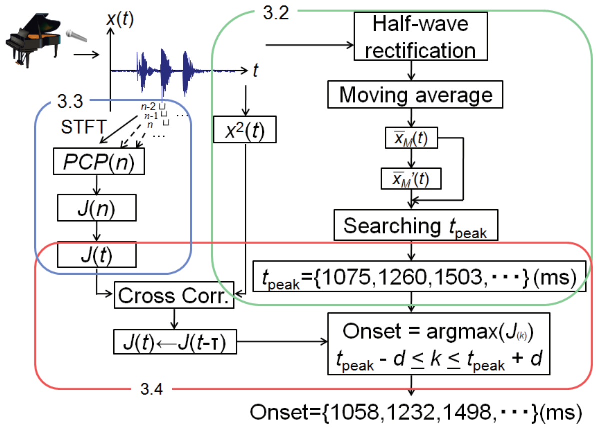

Figure 4. Outline of onset estimation

3.3. Estimation using frequency information

We used PCPs as data based on frequency information. The proposed method uses input sounds sampled at a rate of 44100 Hz and quantized at 16 bits and conducts short-time Fourier transform (STFT) to obtain PCPs along the time axis. An example of calculating PCP for acoustic signal is shown in Fig. 5. After the signal was shifted at intervals of 256 samples (about 6 ms) and fast Fourier transform (FFT) was conducted for the acoustic signal, the signal was transformed to a PCP, represented as a twelve-dimensional vector. A correlation coefficient between consecutive PCPs was obtained to emphasize the change in sounding pitches. When the keyboard is played for the subsequent note, whose pitch is different from the precedent sound, the PCP is expected to be near 0. Otherwise, it is assumed that a certain correlation is obtained. Therefore, it is desirable that the value of the changing point of pitches should be higher and that of the others should be lower by using PCPs. The judging function $J(n)$ is shown in Eq. 1, where $PCP(n)$ is the value of PCP of nth frame and Corr($PCP(n)$, $PCP(n$-1)) is the correlation coefficient between $PCP(n)$ and $PCP(n$-1).

$$J(n) \stackrel{d}{=} \{1-\mathrm{Corr}(PCP(n), PCP(n-1))\}^2 \qquad (1)$$

The calculated $J(n)$ is then converted, using a linear interpolation method, into a function of time t. An example of calculating PCP and $J(t)$ for an acoustic signal is shown in Fig.6.

3.4. Onset detection based on frequency and time information

We used both a judging function with a correlation coefficient between consecutive PCPs $J(t)$ and an acoustic power function $\overline{x}_M(t)$, so that the peak time of $\overline{x}_M(t)$ is used to obtain the onset time. The time of the maximum position of $\overline{x}_M(t)$ does not exactly agree with the changing time of pitch, so there is a temporal difference between the maximum of $\overline{x}_M(t)$ and the actual timing of onset. Moreover, $J(t)$ also has a temporal difference for the actual onset time, because the onset is usually felt after the peak of the waveform [6]. Therefore, the difference should be corrected by observing $x^2(t)$. Consequently, the cross-correlation is calculated between $x^2(t)$ and $J(t)$. The peak time of $J(t)$ is located before the actual onset times because $J(t)$ depends on only the changing time of pitch. Therefore, $J(t)$ should be shifted using the cross-correlation to compensate the time difference between them. An example of the difference between $\overline{x}_M(t)$ and $J(t)$ is shown in Fig. 7. After the time difference is compensated using cross-correlation, the onset time is estimated using $J(t)$ and $\overline{x}_M(t)$. The proposed method obtains the onset time when the value of $J(t)$ is high in the range of $\pm d$ ms of the peak time of $\overline{x}_M(t)$. In this case, the proposed method uses d=50 ms. An example of onset estimation is shown in Fig. 8.

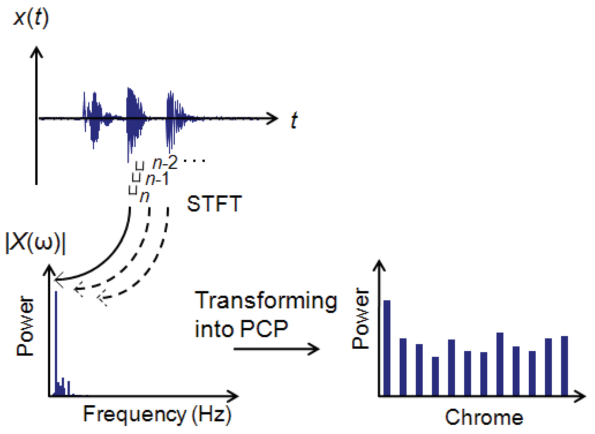

Figure 5. Example of calculating PCP for acoustic signal

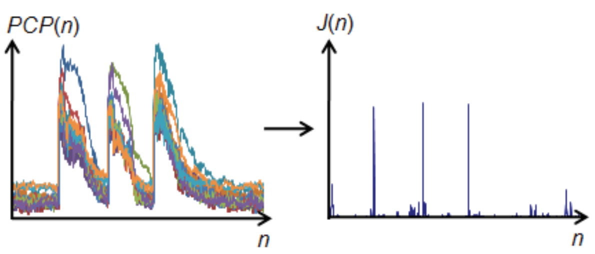

Figure 6. Example of calculating $J(n)$ for acoustic signal

3.5. EVALUATION EXPERIMENT FOR ONSET ESTIMATION

3.5.1. Evaluation experiment

We conducted an evaluation experiment for onset estimation. Specifically, the estimated onset time was compared with correct data. We used the musical score shown in Fig. 3. The 5040 notes evaluated as stimuli were comprised by multiplying 15 notes of a scale by 336 patterns. In addition, the correct data of this experiment were the recorded MIDI signals. To confirm the effectiveness of our proposed method, onset time was estimated using the following two methods.

- The proposed method (MV + PCP)

  Comparatively high value of $J(t)$ obtained around the peak of $\overline{x}_M(t)$ is assumed to be the onset time.

- A simple method using only the time information (MV + Power)

  Comparatively high value of $x^2(t)$ is obtained around the peak of $\overline{x}_M(t)$ is assumed to be the onset time.

There were neither missing notes nor insert notes in all cases, so that just the accuracy rate of the onset time estimated using the proposed method was compared with that recorded using the MIDI signal. The employed conditions of correctness were within ± 10, ± 20, ± 30, ± 40 and ± 50 ms in terms of the time difference between onset time estimated using each method and that of the MIDI signal.

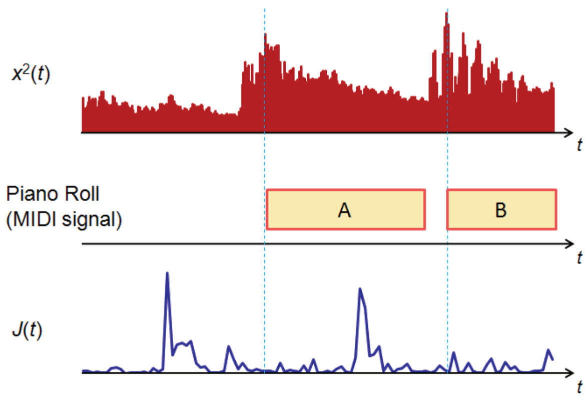

Figure 7. Difference between $\overline{x}_M(t)$ and $J(t)$

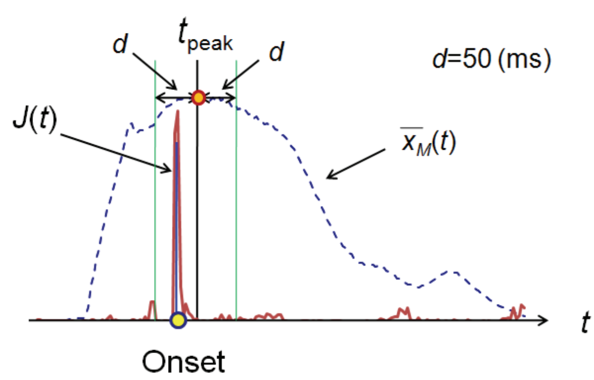

Figure 8. Example of onset estimation

3.5.2. Environmental condition

We used an electronic piano (MOTIF ES8, YAMAHA Co.) connected with a monitor speaker (MSP3, YAMAHA Co.). The playing sound was output from the monitor speaker. A PC-based recorder was used with a USB-audio interface (EDIROL UA-4FX, Roland Co.) using a microphone (SM57, SHURE Co.) located in front of the monitor speaker.

3.5.3. Results of experiment

The results of this experiment are shown in Fig.9, where the criteria for the difference in the performances between the onset time estimated using each method and that of the MIDI signal are shown on the horizontal axis, and their cumulative correct rates are shown on the vertical axis. Consequently, the answer correctness of the proposed method under differences within ± 10, ± 20, ± 30, ± 40 or ± 50 ms corresponds to 28.4%, 55.1%, 74.7%, 86.2% or 94.2%, respectively. In addition, the answer correctness in the case of that the errors are greater than ± 50 ms is only 5.8%. The results show that the proposed method is more effective than the simple method (MV + power) because the cumulative correct rate was comparatively high when using time and frequency information.

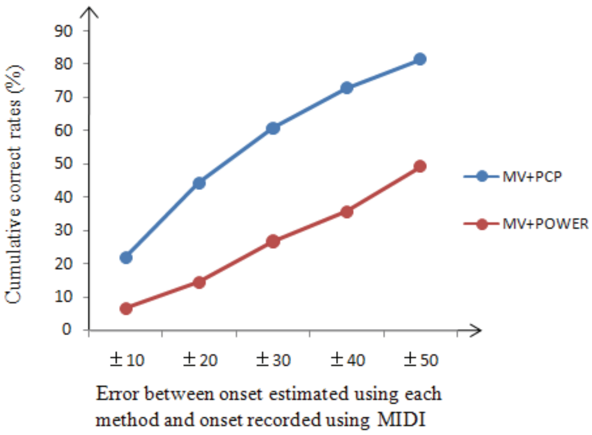

Figure 9. Result of this experiment

4. DURATION ESTIMATION

4.1. Difficulty in estimating duration

Duration estimation means the estimation of how long a piano is played. In this study, when the power of the acoustic waveform attenuated, it was regarded as the offset time. The interval obtained by the subtracting onset time from the offset time was regarded as the duration. An example of duration estimation is shown in Fig. 10, an example of that showing the offset time of a precedent sound and the onset of a subsequent note are located as close to each other on the musical score used in this study. Thus, as shown in Fig.10 (a), it is difficult to identify the power of attenuating sound because the acoustic power of the precedent note is distinguished by the power of the subsequent note. Another case is shown in Fig. 10 (b). It is difficult to estimate the duration correctly because the quantity of acoustic power usually lasts after the actual offset time.

4.2. Outline of duration estimation

As mentioned above, it is difficult to estimate the offset time from an acoustic signal. Therefore, our proposed method estimates the duration using a PCP. Specifically, the proposed method obtains the offset time when a value of a PCP function is judged as low between the onset time of the precedent note and that of the subsequent notes, where the interval by subtracting the onset time from the offset time is regarded as the duration. In the case of duration estimation of the final note during the playing of a scale, the proposed method obtains the offset time when the power of a PCP function attenuates lower than a threshold value. Thus, the interval by subtracting the onset time from the offset time is obtained as the duration of the precedent sound. An outline of duration estimation is shown in Fig. 11.

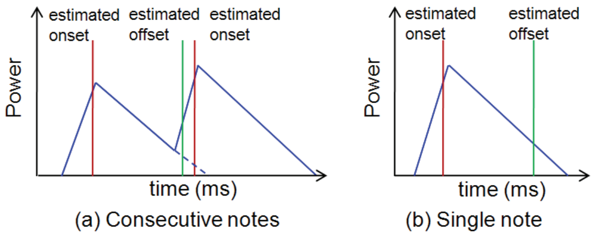

Figure 10. Example of duration estimation

4.3. Correction and threshold value on duration estimation

As mentioned above, the obtained offset time by using PCPs is estimated somewhat earlier than that of a MIDI signal for estimating duration. To investigate the average of differential of estimated onset time between the offset time estimated using the proposed method and that of a MIDI signal were calculated using 420 patterns. It was found that the average of the difference was approximately 40 ms, so the time difference was added to all the offset times. For the final note, the power of PCP at the offset time recorded using a MIDI signal was obtained using 30 patterns. The average of the obtained power was approximately 15 dB, so the amount of the obtained power was used as the threshold value.

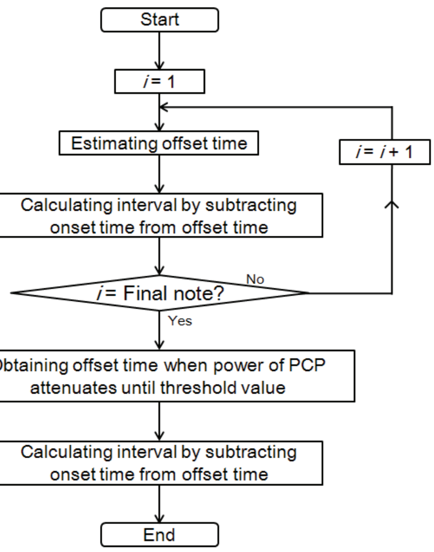

Figure 11. Outline of duration estimation

4.4. Evaluation experiment for duration estimation

4.4.1. Outline of experiment

We conducted an evaluation experiment to estimate duration. Specifically, estimated duration was compared with that of a recorded MIDI signal. We used the musical score shown in Fig. 3 and evaluated the same number of notes (5040) described in Section 3.5.1. The recording environment was the same as described in Section 3.5.2. To confirm the effectiveness of the proposed method, duration was estimated using the following two methods.

- The proposed method

  Offset time is estimated using PCPs.

- A simple method

  Offset time is estimated using only the acoustic power.

The conditions of answer correctness were ± 20, ± 40, ± 60, ± 80 or ± 100 ms in terms of the temporal difference between the duration estimated using each method and that of the MIDI signal.

4.4.2. Results of experiment

The results of the performance evaluation for the musical score are shown in Fig. 12, where the criteria for the temporal difference in the performances between duration estimated using each method and that of the MIDI signal are shown on the horizontal axis, and their cumulative correct rates are shown on the vertical axis. The accuracy rate of the proposed method was higher than that of the simple method in all conditions. Consequently, the answer correctness of the proposed method under differences within ± 20, ± 40, ± 60, ± 80 or ± 100 ms corresponds to 34.9%, 60.0%, 85.1%, 93.3% or 97.6%, respectively. Therefore, we confirmed the effectiveness of our proposed method.

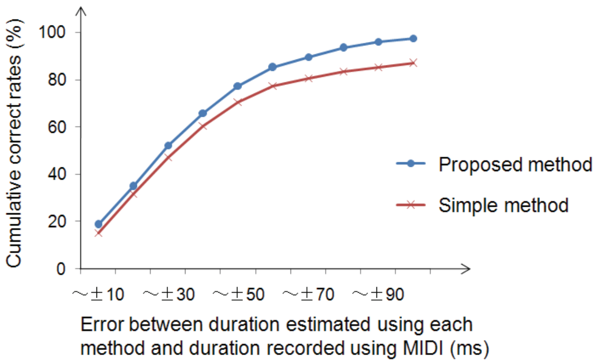

Figure 12. Results of performance evaluation

5. MIDI VELOCITY ESTIMATION

5.1. Difficulty in estimating MIDI velocity

MIDI velocity estimation means estimating the acoustic strength of pressing the keys of a piano. It is expected that the highest power of the acoustic waveform corresponds to MIDI velocity, so the highest power of the acoustic waveform is compared with the MIDI velocity. The proposed method obtains the height of the peak point of the waveform around the estimated onset time, so the power of the peak point is compared with the acoustic power of the already recorded data with wide ranging MIDI velocity. For determining the MIDI velocity of the input sound, the nearest value among the already recorded data was used; therefore, its MIDI velocity was used as that of the played note. An example of MIDI velocity estimation is shown in Fig. 13. For the single note shown in Fig. 13 (a), it is expected to easily estimate the MIDI velocity using the proposed method. However, for the consecutive notes shown in Fig. 13 (b), the sound of the subsequent notes stops before the power of the precedent notes attenuate. Because the precedent note may affect the subsequent note, it is difficult to estimate the MIDI velocity using the proposed method in the case shown in Fig. 13 (b).

5.2. Obtaining MIDI velocity from acoustic power

Here, we describe the recorded data using MIDI velocity. MIDI data with wide ranging MIDI velocity from 1 to 127 for note number 60 were recorded and the acoustic powers of the sounds were obtained. Thus, a 3-dimentional curve was calculated from the calculated power used to estimate MIDI velocity in the proposed method. The power of the recorded piano sound and the 3-dimensional curve are shown in Fig. 14.

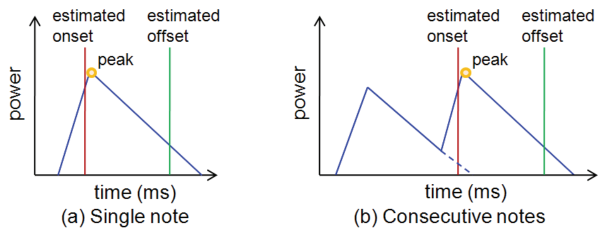

Figure 13. Example of MIDI velocity estimation

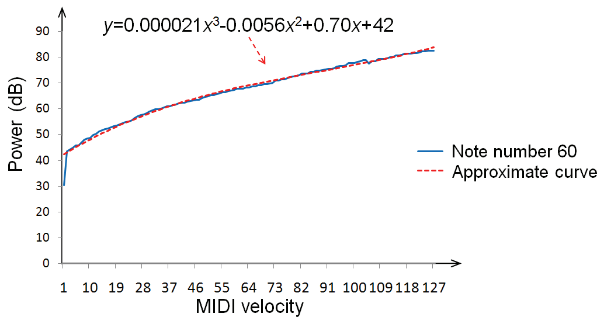

Figure 14. Power of recorded piano sound and 3-dimensional curve

5.3. Outline of MIDI velocity estimation

The proposed method estimates the highest peak point of the waveform around the estimated onset time, so the obtained power is compared with that of the already recorded data with wide ranging MIDI velocity. It is assumed that the height of the peak point is around the estimated onset time because the acoustic power reaches its peak at the pressing of the keys. Thus, the highest power is obtained between *s* ms before the estimated onset time and *e* ms after that. As mentioned above, it is difficult to estimate MIDI velocity of a current note when the precedent sound lasts after the onset of the current note, because it may affect the acoustic power of the current note. In our proposed a method, the MIDI velocity is estimated by dissolving the effects of the precedent note. For estimating MIDI velocity for the first sound on a scale, the MIDI velocity of the first note is estimated by the acoustic power of the onset time estimated and by the method described in chapter 5.2. In estimating MIDI velocity of second note, its MIDI velocity is obtained by observing the acoustic power of the peak time around the estimated onset time of the second note. Next, the previous power of just the precedent sound is obtained. Therefore, the power obtained by subtracting the previous power of the precedent sound from the power of the onset time for the subsequent sound is regarded as the power of the precedence sound for the purpose of obtaining the MIDI velocity of the precedence sound. The previous power of the precedence sound is obtained by observing the smallest value of the curve of moving average $\overline{x}_M(t)$ between the onset time of the precedent note and the onset time of the subsequent note. The obtained power is regarded as the power of the precedent note. An example of MIDI velocity estimation after the first note is shown in Fig. 15. Finally, the list of acoustic power obtained from the playing of the scale is converted into MIDI velocity by observing the list of acoustic power for wide ranging of MIDI velocity. For determining the MIDI velocity of inputted performance, the nearest values for each note are selected. In addition, the power of the precedent sound is estimated using the curve of moving average $\overline{x}_M(t)$ calculated in Section 3.3. The outline of the proposed method for estimating the MIDI velocity is shown in Fig. 16.

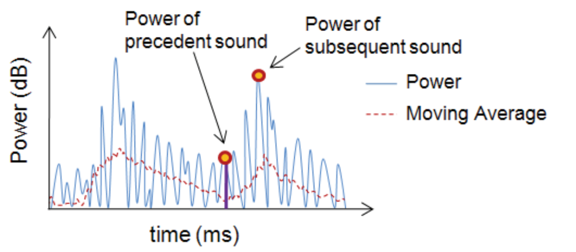

Figure 15. Example of estimating MIDI velocity after first sound

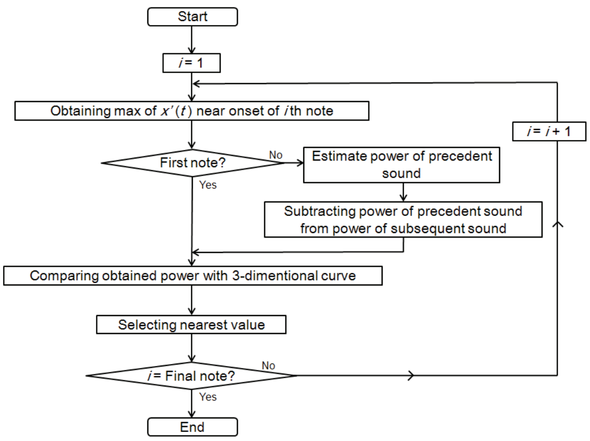

Figure 16. Outline of proposed method for estimating MIDI velocity

5.4. Evaluation experiment for MIDI velocity estimation

5.4.1. Evaluation experiment

We conducted an evaluation experiment for estimating MIDI velocity. As mentioned in Section 5.3, there were the peak points around the estimated onset time, so the highest power was obtained between *t-s* ms and *t+e* ms for the estimated onset time *t*. In other words, the MIDI velocity was estimated using the eight conditions given below. We compared the MIDI velocity estimated using these conditions with that of the MIDI signal and calculated the accuracy rate of the estimated MIDI velocity for each condition.

- Condition T: s is 0 ms.
- Condition T_{-20}: s is 20 ms.
- Condition T_{-40}: s is 40 ms.
- Condition T_{-60}: s is 60 ms.
- Condition T_{-80}: s is 80 ms.
- Condition T_{-100}: s is 100 ms.
- Condition T_{-125}: s is 125 ms.
- Condition T_{-150}: s is 150 ms.

When s is large, the power of the precedent sound maybe be interrupted for obtaining the correct MIDI velocity because the range to be evaluated is comparatively wide. Therefore, an appropriate value of s is required for the eight conditions. The interval between onset times should be 250 ms in the performance in this study. Because the acoustic power attenuates after the keys of the piano were pressed, it is assumed that the correct power of the subsequent note is not obtained when the value of e is set as 150 ms. We used the MIDI velocity recorded by a MIDI signal as the correct data. The employed conditions of answer correctness were ±5, ±10, ±15, ±20 or ±25 in terms of the difference between the MIDI velocity estimated using each method and that of the MIDI signal. This experiment used the musical score shown in Fig. 3 and the same number of notes described in Section 3.5.1. The recording environment in this experiment was the same as that described in Section 3.5.2.

5.4.2. Results of experiment

The results of this experiment are listed in Table 1, where the criteria for the difference in the performances between the MIDI velocity estimated using each method and that of the MIDI signal is shown on the horizontal axis, and their cumulative correct rates are shown on the vertical axis. Consequently, the correctness of the answer rate of condition T_{-60} is the highest of all conditions. The answer correctness of the proposed method under the differences within ±5, ±10, ±15, ±20 or ±25 corresponds to 59.2 %, 73.6 %, 81.2 %, 94.0 % or 99.4 %, respectively. The proposed method estimated onset time later than the actual peak point, so the MIDI velocity was accurately estimated. As a result, condition T_{-60} was confirmed as the best.

Table 1. Results of experiment

Condition	Cumulative correct rates (%)				
	～±5	～±10	～±15	～±20	～±25
T_{-0}	25.3	52.4	67.8	77.6	86.0
T_{-20}	32.0	60.9	76.0	83.6	89.6
T_{-40}	46.2	71.6	81.2	91.8	98.2
T_{-60}	59.2	73.6	81.2	94.0	99.4
T_{-80}	59.2	73.6	81.2	94.0	99.4
T_{-100}	59.2	73.6	80.2	94.0	99.4
T_{-125}	59.2	73.6	80.2	94.0	99.4
T_{-150}	59.2	73.6	80.2	94.0	99.4

6. PROFICIENCY ESTIMATION USING PROPOSED METHOD

6.1. Data for estimating proficiency

We used acoustic data, which were converted from 336 MIDI patterns obtained in a previous study [4] in the same environment described in Section 3.5.2, with proficiency scores obtained in the previous study. Specifically, the proposed method estimates the proficiency score for the 336 acoustic data that had been converted from the 336 MIDI notes.

6.2. Problem in estimating proficiency

The approximate curve described in Section 5.3 was obtained using the sound of only note number 60 from an acoustic piano. The other note numbers were not investigated. For example, the approximate curve was not considered for note number 60. Therefore, the estimated MIDI velocity may affect proficiency.

6.3. Approximate curve for estimating MIDI velocity

An appropriate coefficient for the approximate curve was estimated using the gradient method for solving the problem described in Section 6.1. The approximate curve for estimating MIDI velocity is shown in Eq. 2, where v is the MIDI velocity and p is the power of the acoustic signal of v. The curve is not proficiency scores with various MIDI-velocities. The method for obtaining a renewed coefficient using the gradient method is shown in Eq. 3, where α is a constant value, k is the renewed times of c, and correlation^k is a correlation between a proficiency scores produced using the proposed method and those given by expert pianists.

$$P=0.000021v^3-0.0056v^2+cv^2+42 \quad (2)$$

$$c^{k+1}=c^k-\alpha P'+(\text{correlation}^{k-1}-\text{correlation}^k) \quad (3)$$

In addition, the condition of stopping the repeating computation of gradient method is shown as $|\text{correlation}^{k-1}-\text{correlation}^k|<0.001$, that the obtained value of c is 0.75. The proposed method estimates the proficiency scores using the onset time, duration, and MIDI velocity estimated using the proposed method. An acoustic signal was investigated, and learning data of the acoustic signal are required. Therefore, 15 parameters were calculated from the onset time, duration, and MIDI velocity, and these parameters were compressed into four components using the principal component analysis. Finally, four parameters were obtained for learning data.

6.4. Results of proficiency estimation considering the problem

The correlation coefficient between the proficiency scores produced using the proposed method and those given by expert pianists was .520 (n=336) before renewing c in Eq. 2, and the correlation coefficient was .578 (n=336) after renewing c in Eq. 2. Using the approximate curve calculated using gradient method makes it possible to estimate the proficiency scores more accurately. The results of this experiment are shown in Fig. 17. As the result, the correlation coefficient between the proficiency scores produced using the proposed method and those given by expert pianists was .578 (n=336, **: p<.01); therefore, we confirmed that the proposed method can be used to estimate proficiency scores.

7. CONCLUSION

In this study, notes played on a piano were converted into a MIDI signal, in order to develop a support system for use with an acoustic piano. Specifically, the proposed estimates the onset time, duration, and MIDI velocity from an acoustic signal, and moreover, the proposed method estimates proficiency using MIDI notes. We conducted an evaluation experiment for estimating the onset. The proficiency scores produced using the proposed method were compared with those given by expert pianists. In addition, the correlation coefficient was calculated from these scores. Therefore, the correlation coefficient between the proficiency scores produced using the proposed method and those given by the expert pianists was .578 (n=336, **: p<.01). From these results we confirmed the effectiveness of the proposed method. Future work is that to improve the accuracy of estimating duration, so that the proposed method can be used to accurately estimate proficiency.

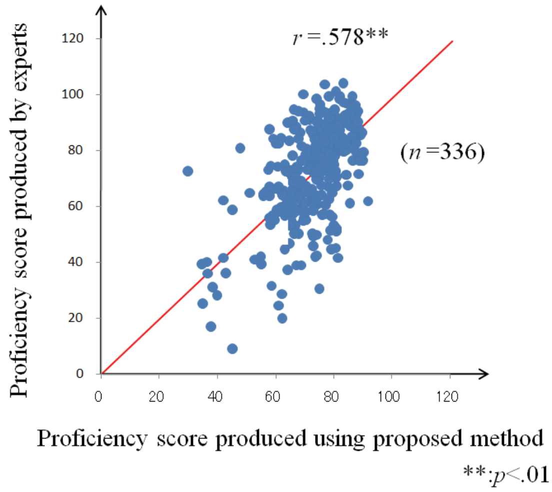

Figure 17. Result of this experiment

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