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Evaluation parameters for proficiency estimation of piano based on tendency of moderate performance

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ABSTRACT

This paper describes an automatic estimation for piano performance in terms of the proficiency for an etude "Czerny". Our previous study proposed a method of proficiency estimation for a scale performance within one octave by the MIDI-piano, in which a set of parameters were obtained and then applied to the automatic estimation. However, it is not sufficient to simply employ them to other musical excerpts, since the piano performance usually has several complex aspects such as artistic expression or so. Here we introduce another set of parameters for the automatic estimation for other musical task "Czerny". Even though the content of the task is thought as simple because of the simple equal intervals, players might produce deviation of loudness, tempo, and/or onset from equal timing. We then newly introduce several parameters concerning tempo, duration, velocity, onset time, normalized tempo, normalized duration, normalized velocity, normalized onset, slope tempo, slope duration, slope velocity, and slope onset, where the normalized parameters mean the average of all performances, named here as moderate performance. By using the Principle Component Analysis for all the obtained parameters, we then obtained principle components for them. A simple determination method (*k*-NN) is employed to calculate the proficiency score of them. Results shows that correlation coefficient of proposed method are 0.798, 0.849, 0.793 and 0.516, for task A of 75 (bpm) and 150 (bpm), and task B of 75 (bpm) and 150 (bpm), respectively, showing the effectiveness of proposed method.

I. INTRODUCTION

Since "artistic deviation (Seashore, 1938)" was defined using deviation from musical scores in musical performances, various features of performance relevant to it such as characteristic contrast, impression, and emotion have been studied (e.g. Kotlyar *et al*., 1976, Senju *et al*., 1987, Slobida, 1983, Repp, 1992). These studies, however, have not dealt with performance proficiency, except for one that estimated the proficiency of piano performances on the basis of a spline curve representing global tendency of current performance (Akinaga *et al*., 2006). The task in that study was restricted to a scale of one octave. To lift this restriction, we tried to estimate the proficiency for Czerny a piano etude (Nonogaki *et al*., 2011) by simply using our previously proposed method (Akinaga *et al*., 2006). Although the performance task in the study included dynamic marks such as "*p*(piano)" or "*cresc*.(crescendo)", the study introduces no evaluation parameters for those marks that show particular aspects of performance tasks. Here explains the set of parameters that is newly introduced so as to precisely estimate the proficiency of recorded performance of Czerny. This study uses 9 bars out of Czerny's 40 etude as the performance tasks, as shown in Figure 1 and Figure 2. Originally, the tempo of the task was specified as 208 (bpm), but we changed it to 75 and 150 (bpm), since the original is felt as fast for most of subjects. These performance tasks are labeled as "A75", "A150", "B75", or "B150", for 75 (bpm) of task A, 150 (bpm) of task A, for 75 (bpm) of task B, or 150 (bpm) of task B, respectively. The numbers of recorded performances are 200, 196, 195, or 185 for A75, A150, B75, or B150, respectively. All the performances are done by three professionals and 20 students majoring piano performances. The number of performance is not consistent among players, but normally they play approximately 10 times. Employed piano is a Bösendorfer SEUS.

II. DESCRIPTION OF PERFORMANCE BY SEVERAL STANDARDS

The estimation of proficiency usually requires several

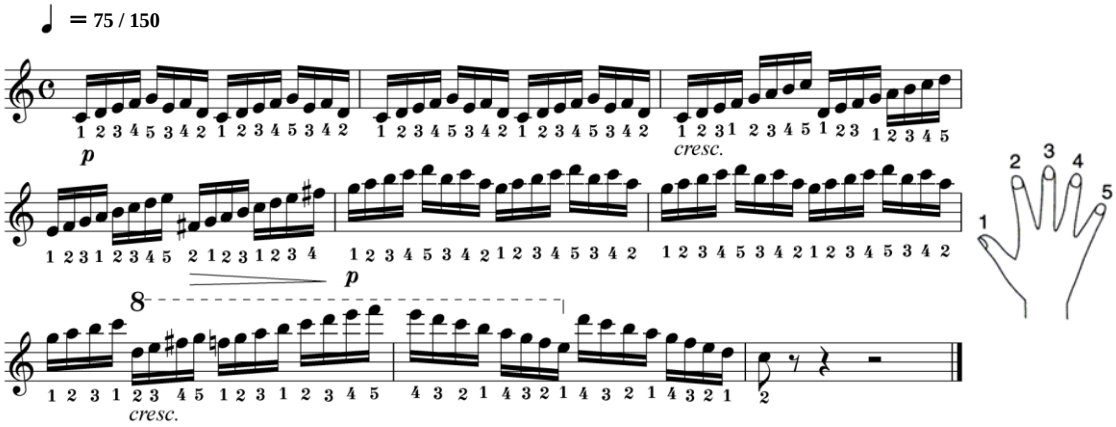


Figure 1. Performance task A employed in this paper.

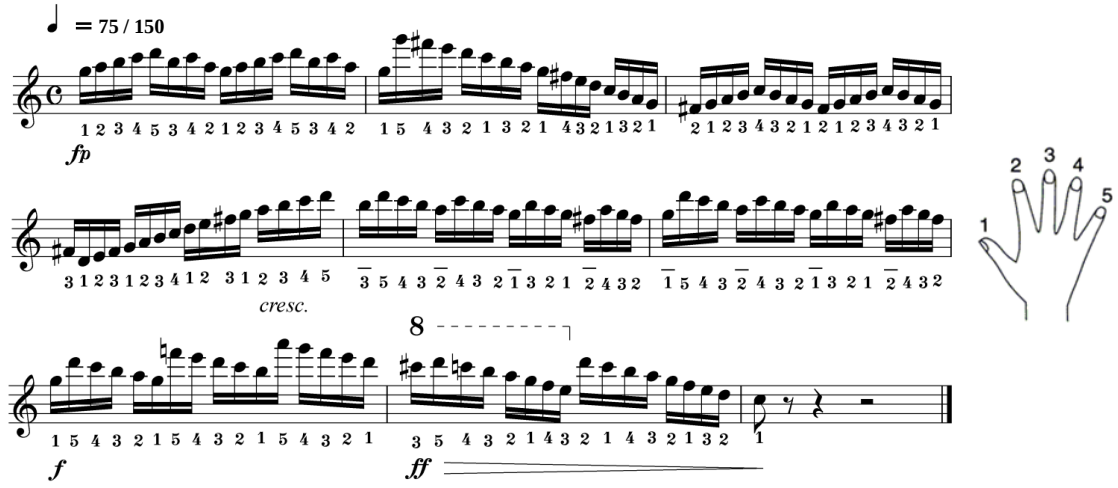


Figure 2. Performance task B employed in this paper.

aspects of obtained performance. However, the appropriate aspect of the performance has not been clear. Moreover, on using the MIDI piano, we do not have so much information for the performance, such as onset, velocity and duration only. From such limited information, we need to describe the appropriate aspects of performance. Here we explain the method, by using a couple of standards for obtained MIDI performance. Concretely, three types of standards are introduced; constant standard, tendency standard, and musical standard.

2.1 Constant Standard

The constant standard is the simplest standard. In case of MIDI-velocity and duration, a simple standard is a constant value, such as 64 for MIDI-velocity, or ideal interval among notes under given tempo (200 (msec), for 75 (bpm) in Figure 1). Obtained data are subtracted by the constant standard and then analyzed. In case of the onset, we have two types of standards. One is the given standards, which means the metronomic timing, and the other is the generated standards, that mean a straight line tendency obtained by the onset times between initial and final note. Since the players tend to play with slight changes of tempo, the difference from the straight line is expected to be useful. Figure 3 shows an example of generated standard for onset. As can be seen in Figure 3, the onset timing is becoming prior to the generated standard, so it shows that the performance is accelerating at the first stage and then it become slower.

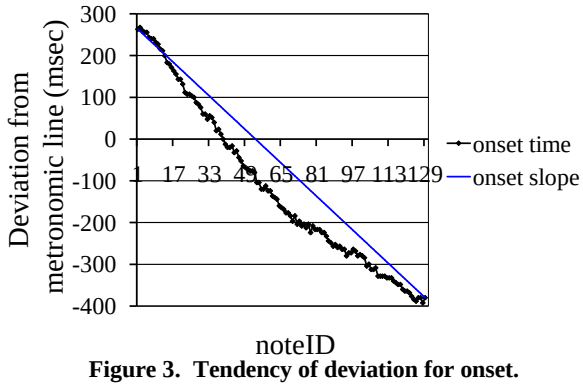


Figure 3. Tendency of deviation for onset.

2.2 Gradual Standard

Besides the entire tendency represented by the constant standard, piano performance often shows gradual changes, which means so-called agogik or artistic deviation of performance. The deviation is assumed here to be occurred in shorter duration compared to the entire tendency. The gradual changes are thought to be depending on their expression, habit of fingers, and so forth. Then the modeling of it is though as hard, for the difficulty of ensuring the validity itself. Here we use a spline curve as the gradual standard of the performance, where spline curve is to be set to pass the specified points. Here the points are set the position of wrist of hand. In addition, in our previous study, the determination method for the representative points of the spline curve was based on the sequence of notes by dividing them into several clusters comprised of several notes, based on the "crossing" and "turning" of the fingering when playing. Then, the center in each cluster is regarded as the representative points of each cluster. Therefore, by using the spline curve, we can take into consideration the characteristic of hand movement on the automatic estimation.

2.3 Musical Standard

There is no doubt that the artistic deviation is mainly affected by musical score. Even though a diversity of performances among players for a musical score is shown, there are common features among the performances. It is because the players need to make a strategy how to play it based on the musical score in a certain degree. Even though the task employed here contains several specifications for dynamics shown in Figure 1 and Figure 2, it will be allowable to assume that not only dynamics but also onset and duration may have some common feature among players. Therefore, we obtained the average performance of the task. We named it as a "normalized performance". Figure 4 shows the MIDI-velocity for a normalized performance of the given task. The MIDI-velocity of normalized performance is obtained by a simple average for all the obtained performance data. In other words, MIDI-velocity for each note is averaged across all performances. The instruction of dynamics on musical score is also shown in Figure 4. As can be seen in Figure 4, the

MIDI-velocity depends strongly on the instruction on musical score, whereas some characteristic curve independent to the instructions is also shown. So it shows a possibility that a certain common aspect exist among players.

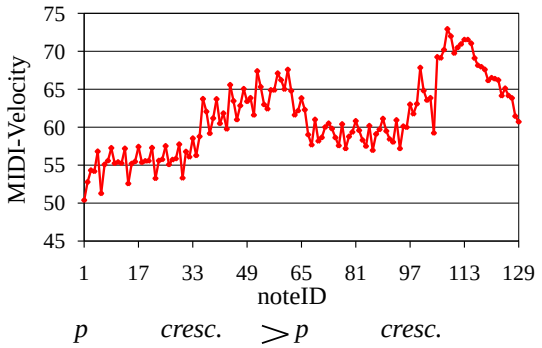


Figure 4. Tendency of MIDI-velocity with dynamics on Figure 1.

III. EVALUATION PARAMETERS

3.1 Curves to be Analyzed

Here explains the parameters to be applied for automatic estimation. The list of parameters with relations among parameters is shown in Figure 5. After obtaining the conventional recorded performance, we will obtain the difference of the conventional performance from constant standard such as metronomic line or so, that is labeled here as *x*', Then for the sequence of *x*', we will obtain the spline curve for it, and then by subtracting the spline curve from *x*', the difference is obtained, labeled as *x*''. On the other hand, we will have an average for all the recorded data and then we will obtain the normalized performance, labeled as x^{all}.

3.2 Aspects to be Considered

The list of performance data to be considered is as follows;

- Onset

The onset time is given by simple MIDI data, which is represented by MIDI-tick.

- MIDI-velocity

The MIDI-velocity is also given by simple MIDI data.

- Duration

The MIDI-duration is also given by simple MIDI data, as a time interval between onset and offset.

- Tempo

The tempo means the interval of adjacent two notes, it might be labeled as spontaneous tempo, but here we simply label it as tempo. The interval of the notes is represented by msec and then converted into bpm. In order to avoid the rapid change of spontaneous tempo due to unintended gaps such as delay of key pressing, the moving average for among six notes including the current note are then conducted.

- Slope Onset

As explained in section 2.1, onset time for considering the

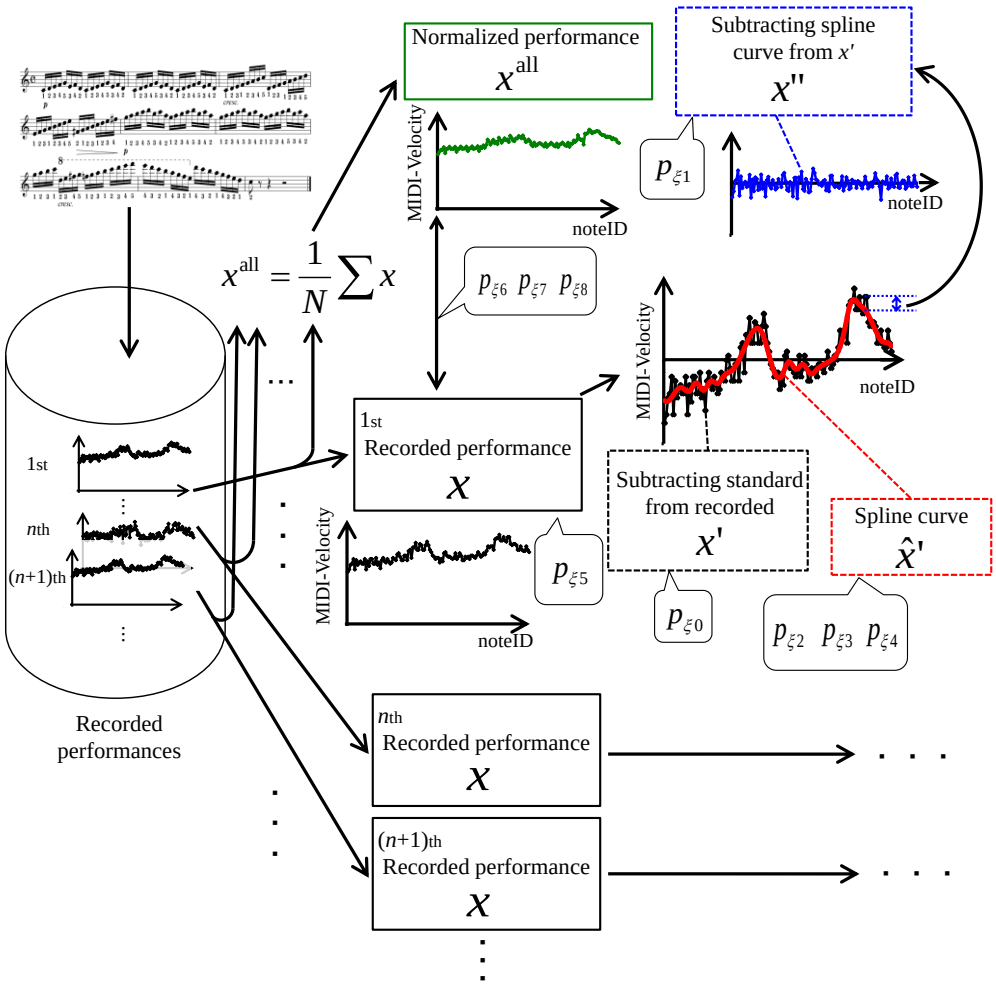


Figure 5. Parameters.

generated standard is employed as the onset slope. It is a subtraction of onset from straight line assumed as the generated standard, as shown in Figure 3.

- Slope MIDI-velocity

The slope MIDI-velocity is obtained in the same way of slope onset.

- Slope Duration

The slope duration is obtained in the same way of slope onset.

- Slope Tempo

The slope tempo is obtained in the same way of slope onset.

- Normalized Onset

The normalized onset is obtained by a simple average across all the recorded performances (200, 196, 195 or 185 patterns), given by

$$a_{\xi k} = \frac{1}{N}\sum_{l=1}^{n} x_{kl} \ , \qquad (1)$$

where the a represents the normalized data, ξ means the specific parameter such as onset, MIDI-velocity, duration and so forth, k means note ID ($1 \le k \le 129$), and N means the number of data (200 for A75, 196 for A150, 195 for B75, or 185 for B150).

- Normalized MIDI-velocity

The normalized MIDI-velocity is obtained in the same way of normalized onset. The equation (1) is also used.

- Normalized Duration

The normalized duration is obtained in the same way of normalized onset. The equation (1) is also used.

- Normalized Tempo

The normalized tempo is obtained in the same way of normalized onset. The equation (1) is also used.

3.3 Parameters

The parameters that show specific aspect of performance are introduced. They are labeled as $P_{\xi 0}$ to $P_{\xi 8}$, where ξ means the specific parameter such as onset, MIDI-velocity, and so forth.

- P_0 is the standard deviation of x'. It is a generally accepted parameter to know the amount of deviation for performances.
- P_1 is the rms of x'', which means the deviation from spline curve of the performance. If the P_1 is large, the performance is assumed as to have a large deviation under a constant hand position. On the other hand, in case the P_1 is small, the performance shows moderate performance.
- P_2 is the range of spline curve. Observed performances sometimes have sudden changes due to unintended movement of fingers or inadequate skill of fingerings. This parameter can ignore such situations, since P_2 is obtained by the spline curve.
- P_3 is the rms of the difference of spline curve between adjacent notes. The P_3 is expected to reveal the degree of change for spline curve from constant standard.
- P_4 is the sum of spline curve, showing the average difference from constant standard.
- P_5 is the slope of recorded performance, and it is only for the slope onset. If the P_5 is large, it means that the whole change of tempo is large.
- P_6 is sum of the difference between recorded and normalized performance. It shows a basic aspect of current performance in terms of similarity.
- P_7 is sum of the absolute difference between recorded and normalized performance for each note. It is a more detailed aspect of current performance in terms of similarity.
- P_8 is the coefficient of determination of recorded for normalized performance, showing the statistical similarity among them.

IV. AUTOMATIC ESTIMATION METHOD

The flow of proposed method for obtaining estimation score of piano proficiency is shown in Figure 6. The recorded performance is obtained by the MIDI piano, and then a set of parameters for the automatic estimation is obtained and is represented as a vector. The dimensions for the obtained vector are compressed by using the PCA (Principle Component Analysis). The estimation score is then obtained using the *k*-NN algorithm. Here employs the 12 principle components whose cumulative contribution ratio is more than 90%. Concretely, the nearest seven performances for the inputted are chosen then the average of subjective scores given by expert pianists for the seven neighborhoods is obtained and it is regarded as the estimation score. To realize the automatic estimation, it requires the estimation score for all the performances.

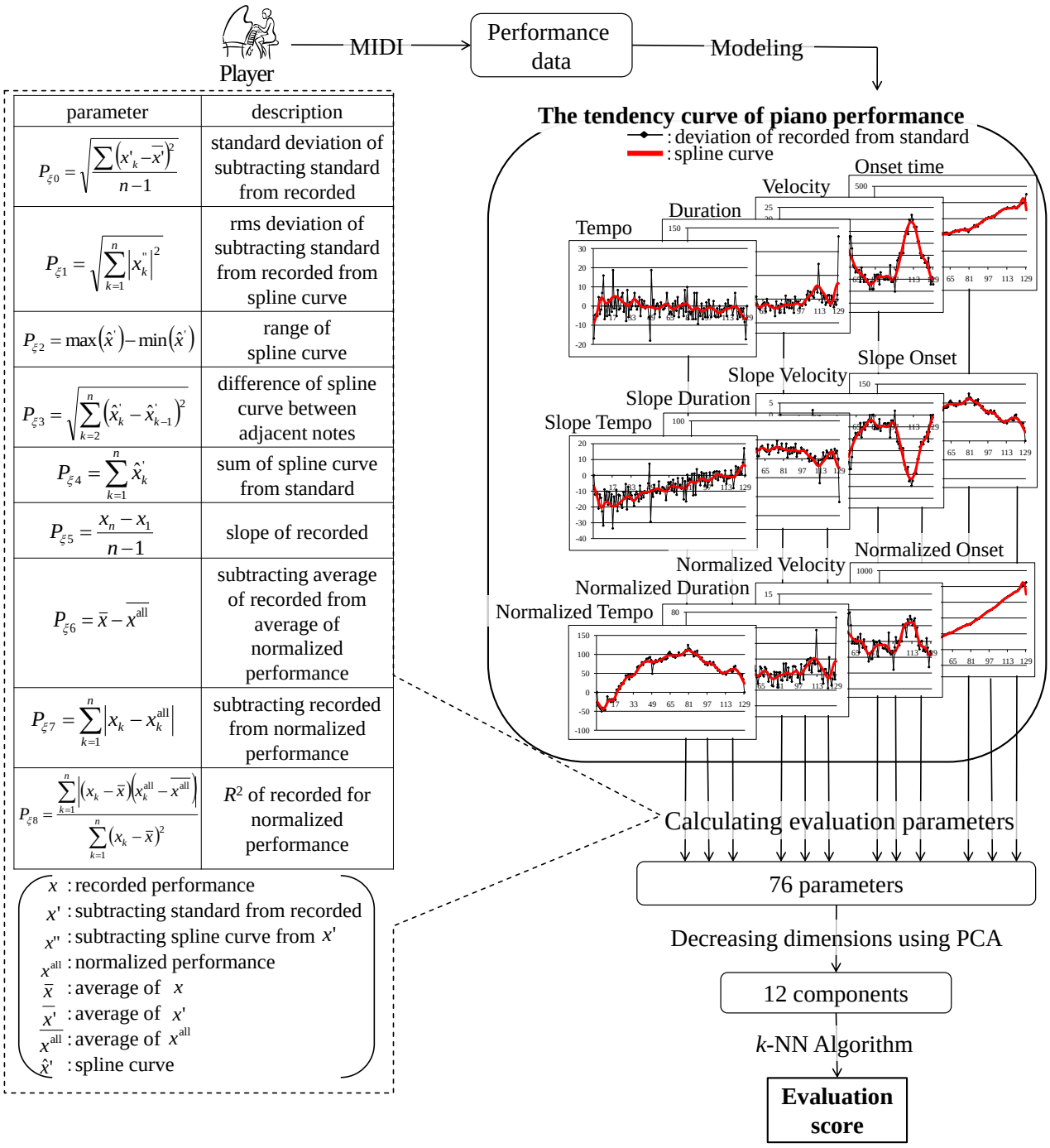
V. RELATION BETWEEN EVALUATION PARAMETERS AND EVALUATION SCORES

Evaluation parameters described in section III were calculated for all tasks. The total number of parameters is 76 for each task. To confirm the validity of the parameters, relations between the parameters and evaluation scores are evaluated.

5.1 Comparison of Evaluation Parameters with Evaluation Scores

The correlation coefficient between each obtained parameter and evaluation score given by 8 expert pianists was obtained for all parameters and for 4 tasks. Here the expert pianists were asked to evaluate the piano performance in ten steps of 1 – 10 (10 is the best) in terms of proficiency. The correlation coefficients between each parameter and averaged evaluation score given by eight expert pianists are shown in Figure 7. Although several parameters have a strong correlation to evaluation score, the amount of correlation depends on the task. The range and the average of correlation coefficients are 0.016 – 0.698 (0.341) for A75, 0.000 – 0.552 (0.279) for A150, 0.005 – 0.743 (0.313) for B75, and 0.002 – 0.264 (0.090) for B150. So it implies that the amount of precise description of the proposed parameter depends on the task and tempo.

The correlation of 76 parameters among tasks is also evaluated in order to confirm the consistency of the value of parameters among tasks. Although the value of parameters has strong correlations among A75, A150, and B75 (0.546 – 0.948), the one with B150 shows negative coefficients (-0.209 – -0.551). Then it shows that the evaluation criteria for the B150 differ from other tasks. It implies that kinds of constant value of



parameter	description
$P_{\xi 0} = \sqrt{\frac{\sum (x'_k - \overline{x'})^2}{n-1}}$	standard deviation of subtracting standard from recorded
$P_{\xi 1} = \sqrt{\sum_{k=1}^{n} \lvert x''_k \rvert^2}$	rms deviation of subtracting standard from recorded from spline curve
$P_{\xi 2} = \max(\hat{x}') - \min(\hat{x}')$	range of spline curve
$P_{\xi 3} = \sqrt{\sum_{k=2}^{n} (\hat{x}'_k - \hat{x}'_{k-1})^2}$	difference of spline curve between adjacent notes
$P_{\xi 4} = \sum_{k=1}^{n} \hat{x}'_k$	sum of spline curve from standard
$P_{\xi 5} = \frac{x_n - x_1}{n-1}$	slope of recorded
$P_{\xi 6} = \overline{x} - \overline{x^{\mathrm{all}}}$	subtracting average of recorded from average of normalized performance
$P_{\xi 7} = \sum_{k=1}^{n} \lvert x_k - x_k^{\mathrm{all}} \rvert$	subtracting recorded from normalized performance
$P_{\xi 8} = \frac{\sum_{k=1}^{n} \lvert (x_k - \overline{x})(x_k^{\mathrm{all}} - \overline{x^{\mathrm{all}}}) \rvert}{\sum_{k=1}^{n} (x_k - \overline{x})^2}$	R^2 of recorded for normalized performance

x : recorded performance
x' : subtracting standard from recorded
x'' : subtracting spline curve from x'
x^{all} : normalized performance
$\overline{x}$: average of x
$\overline{x'}$: average of x'
$\overline{x^{\mathrm{all}}}$: average of x^{all}
$\hat{x}'$: spline curve

Figure 6. Flow of proposed method for obtaining estimation score for piano proficiency.

the obtained performance are not useful for describing the proficiency of performance.

By observing the value of correlation coefficient for each parameter, some interesting points are shown. The slope onset P_5 shows strong negative correlation for 3 tasks, which implies that the accelerating performances tend to be evaluated as good. This is in some sense agreeable since the original tempo is faster than specified so the evaluators may think the faster performance is better. The slope onset P_0, P_1, P_2, and P_3 also show negative correlations, which show that the performances whose onset is changing on straight line tend to be evaluated as good. It implies that the onset interval should be changing with constant differences. The slope onset P_4, however, shows positive correlation, which shows that performances with different average from slope tend to be evaluated as good. The parameter shows the deviation from slope is positively evaluated. The normalized parameter is a in some sense a confirmation of the statement of the important previous study (Repp, 1999), which introduced that the average performance could be regarded to have a best aspect of performance. Our results show consistent results from the study, since lots of correlations shows negative correlations such as normalized onset P_0, P_1, P_2, P_3, and normalized duration P_0, P_1, P_4, P_6, P_7, and so forth. Interestingly, some of them such as tempo P_4 and P_6 show positive correlations, which show different results, being expected to show aspects that the normalized performance cannot represent. The novel aspect of the performance should be discussed in the next stage.

5.2 Comparison of Estimation Score with Evaluation Scores

As described in section 5.1, the correlation coefficient in Figure 7 shows the importance of parameters in terms of linear relation between them. On the contrast, if they have other correlation patters except for the linear relation, the correlation coefficient is not able to represent it correctly. In order to investigate the parameter's nature for the correlation to the evaluated score by expert pianists, we explore a new method. We estimated proficiency score by employing only one parameter among 76 parameters by using the method described in section IV, and obtained the correlation coefficient between the evaluation scores given by automatic estimation and those by expert pianists. In other words, we will obtain 76 patters of estimation scores for a task. The method is thought as an investigation method for the correlation between them as a non-parametric manner.

These correlation coefficients are shown in Figure 8, as in the same manner of Figure 7. Unlike the correlation coefficients described in Figure 7, lots of coefficients for A75 and B75 show higher score such as those nearly 0.7 than others. Moreover, most of the parameters with high scores are identical with evaluation parameters strongly correlated with expert pianists' score in section 5.1. Then we evaluated the correlation between absolute value of coefficients in Figure 7 and those in Figure 8. The correlation coefficients of them are 0.855, 0.703, 0.783, and 0.195 for A75, A150, B75, and B150, respectively, which shows that they have linear correlations between parameters and estimated scores. Although we found some exceptions, the relation between the parameter and evaluation scores might have linear relations.

As well as the results in Figure 7, the MIDI-velocity is found to be less important than onset or duration, which shows that the artistic deviation on the Czerny piano performance is realized by mainly time information, being a consistent result with lots of studies for artistic deviation.

Specifically in the parameters of P_6, P_7, and P_8 for normalized onset, duration, and tempo, the parameters shows the importance of the similarity for normalized performance. The P_6 roughly shows the similarity, whereas the P_7 is more precise representation and the P_8 is the precise information of the similarity for the normalized. Interestingly, for the normalized time information, the P_6 and P_7 shows relatively high score whereas the P_8 shows relatively low scores, which implies that the better performances should be similar to the normalized performance but not necessarily being consistent with the normalized performance. As the previous study shows the normalized performance can be thought as a goal of good performance, it cannot show all the aspects of proficiency.

In analogy with section 5.1, however, for B150, all relations between the evaluation scores given by automatic estimation and expert pianists have weak positive or negative correlations. The negative correlation in Figure 8 might show a problem that the parameters cannot describe the proficiency of the performance well.

In order to make sure the effectiveness of the difference of standard such as original, slope, and normalized, we compared the correlation coefficients between the evaluation scores given by expert pianists and those by automatic estimation, where the employed parameters are for $P_0 - P_4$ for original, gradual (only slope) and normalized parameters. The correlation coefficients for the parameters of gradual standard are entirely lower than other standards. Then the correlation coefficients for the parameters of normalized standard are relatively higher than other standards. So, we can say that the parameter concerning the normalized performance shows better results when estimating proficiency for piano performance.

The correlation coefficient between A75 and B75 in Figure 8 is 0.820, and that between A150 and B150 in Figure 8 is 0.038. Moreover, the correlation coefficient between A75 and A150 in Figure 8 is 0.563, and that between B75 and B150 in Figure 8 is 0.524. These results suggest that the parameter relatively depends on task, not tempo. On the other hand, a similar tendency on the parameter among those on 75 (bpm) is shown, whereas there is no similar characteristics among those on 150 (bpm).

5.3 Comparison among Expert Pianists

In order to evaluate the consistency of evaluation among expert pianists, the averages of correlation coefficients between expert pianists in terms of evaluation score are obtained, such as 0.334, 0.366, 0.249, and 0.285, for A75, A150, B75, and B150, respectively. Although the result of evaluation by expert pianists shows in some sense variability among them, the result of evaluation is somewhat consistent among expert pianists.

VI. VALIDITY OF PROPOSED METHOD

For the evaluation of the validity of proposed method, we need to compare it with other methods. Here we employ three simpler methods. Again we need to notify that the flow of automatic estimation is consistent among the four methods except for only the usage of parameters.

- The first one for comparison is a set of parameters on our previous study (Akinaga *et al*., 2006), which tried to estimate a simple scale performance within one octave, where the five parameters for P_0, P_1, P_2, P_3, and P_4 are obtained for onset, MIDI-velocity, and duration. So totally the 15 parameters were employed. Here we also employ the 15 parameters, and label it as "Akinaga(2006)".
- The second one for comparison is almost same as Akinaga(2006) but we add the parameter P_0, P_1, P_2, P_3, and P_4 for spontaneous tempo. Then total number of parameters is 20, labelled as "Nonogaki(2011)".
- The third one is the proposed method. We add the parameter P_0, P_1, P_2, P_3, P_4,and P_5 for slope onset, slope MIDI-velocity, slope duration, slope tempo, and P_0, P_1, P_2, P_3, P_4, P_6, P_7, and P_8 for normalized onset, normalized MIDI-velocity, normalized duration, normalized tempo to parameters of Nonogaki(2011). Then total number of parameters is 76.
- The fourth one for comparison is the method using a part of all parameters in the proposed method. The parameters are picked up by observing the correlation coefficient to the scores given by expert pianists. They have the highest 15 parameters in terms of correlation coefficient. These parameters are P_0 and P_4 for onset, P_0 and P_4 for duration, P_3 and P_4 for tempo, P_5 for slope onset, P_0, P_3 and P_5 for

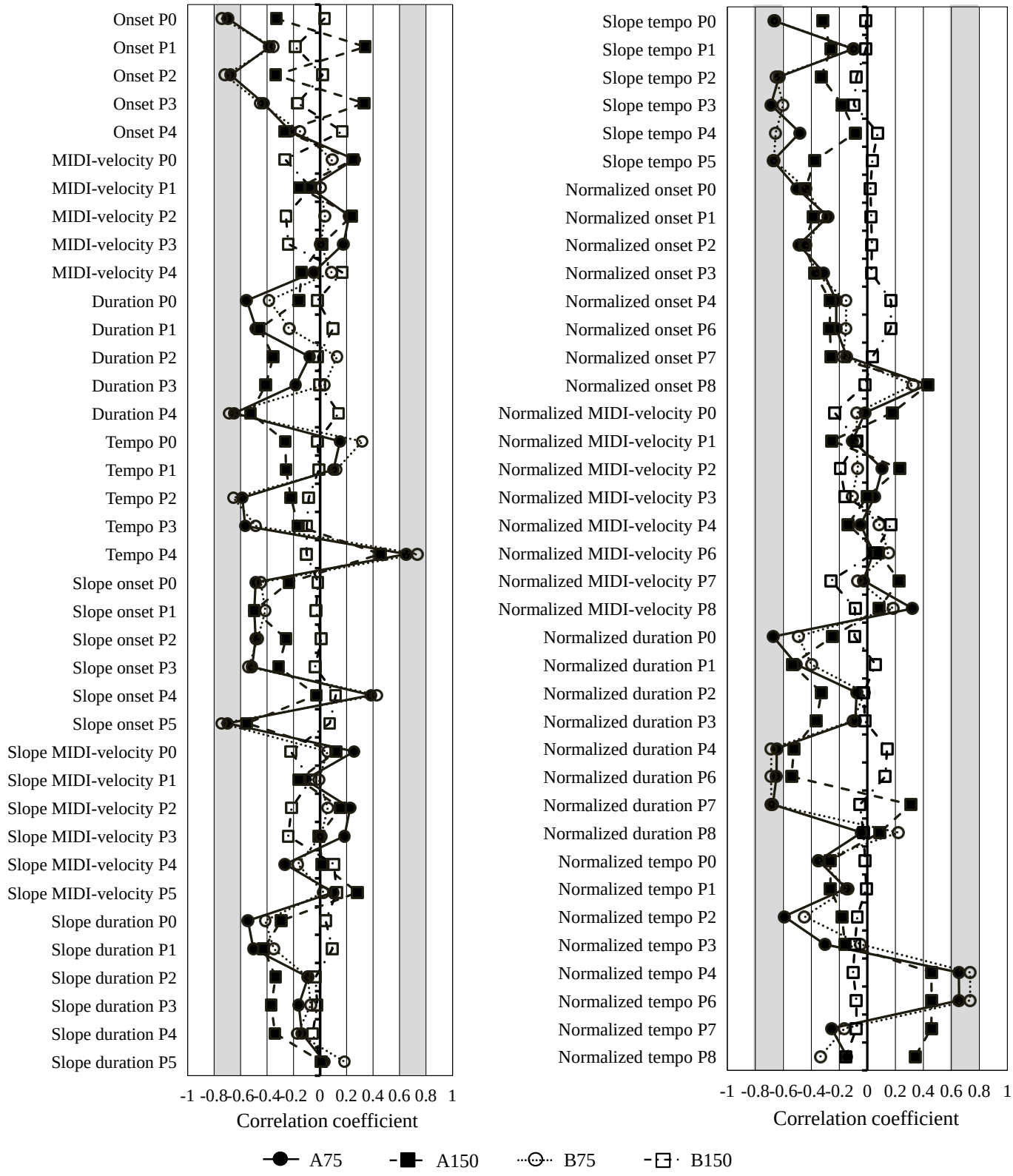


Figure 7. The correlation coefficients between each parameter and averaged evaluation score given by expert pianists for all parameter and for all tasks.

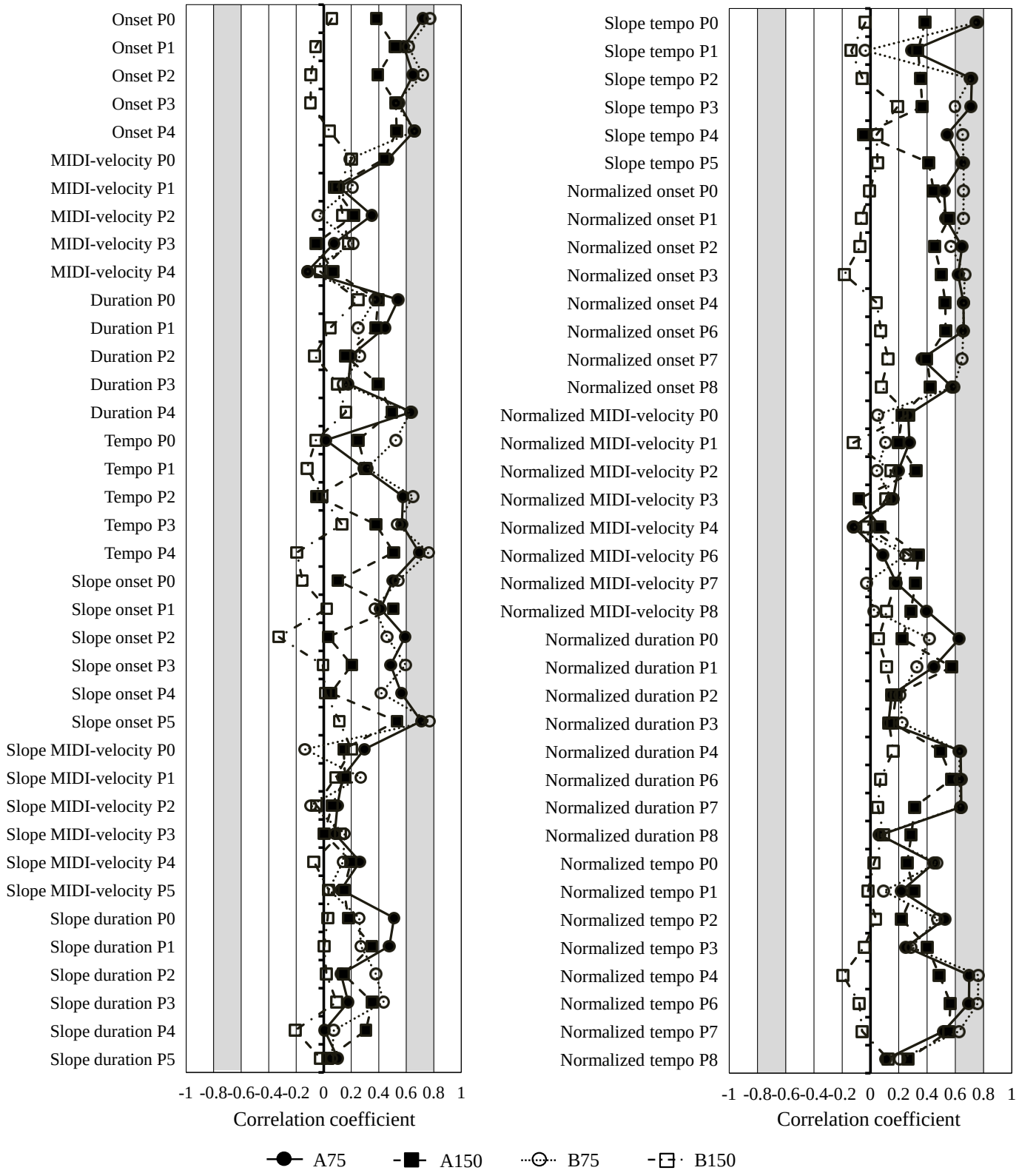


Figure 8. The correlation coefficients between the evaluation scores given by automatic estimation and expert pianists.

Table 1. List of parameters employed on estmation.

	Akinaga (2006)	Nonogaki (2011)	Proposed	Top 15
onset time, velocity, duration	p_0	p_0	p_0	$p_{0(\text{onset, duration})}$
	p_1	p_1	p_1	p_1
	p_2	p_2	p_2	p_2
	p_3	p_3	p_3	p_3
	p_4	p_4	p_4	$p_{4(\text{onset, duration})}$
tempo	p_0	p_0	p_0	p_0
	p_1	p_1	p_1	p_1
	p_2	p_2	p_2	p_2
	p_3	p_3	p_3	p_3
	p_4	p_4	p_4	p_4
slope (onset, velocity, duration, tempo)	p_0	p_0	p_0	$p_{0(\text{tempo})}$
	p_1	p_1	p_1	p_1
	p_2	p_2	p_2	p_2
	p_3	p_3	p_3	$p_{3(\text{tempo})}$
	p_4	p_4	p_4	p_4
	p_5	p_5	p_5	$p_{5(\text{onset, tempo})}$
normalized (onset, velocity, duration, tempo)	p_0	p_0	p_0	p_0
	p_1	p_1	p_1	p_1
	p_2	p_2	p_2	p_2
	p_3	p_3	p_3	p_3
	p_4	p_4	p_4	$p_{4(\text{onset, duration})}$
	p_6	p_6	p_6	$p_{6(\text{onset, duration, tempo})}$
	p_7	p_7	p_7	p_7
	p_8	p_8	p_8	p_8

: not employed
: not defined

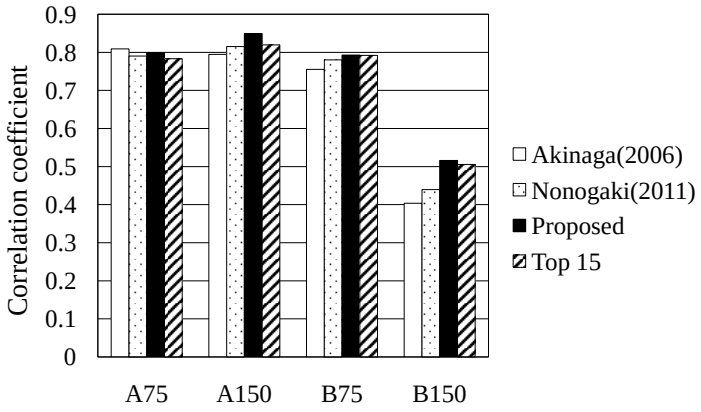


Figure 9. Result of experiment.

slope tempo, P_4 and P_6 for normalized onset, P_4 and P_6 for normalized duration, and P_6 for normalized tempo. Then total number of parameters is 15, labelled as "Top 15".

All the parameters on each method are shown in Table 1, where the columns with diagonal line represent the parameters not used and those filled with black represent those not defined. The important difference among the method is the usage of standard. The first and second one adds the gradual standard but only the spline curve. The proposed method and fourth one adds the musical standard represented by normalized performance.

VII. RESULTS

For the 200, the 196, the 195 and the 185 samples, the correlation coefficients between the evaluation scores given by automatic estimation and expert pianists were obtained to confirm the proposed method's effectiveness. The correlation coefficients were 0.809, 0.790, 0.798, and 0.783 for each method for the A75 condition. The ones for A150 were 0.794, 0.815, 0.849, and 0.820. The ones for B75 were 0.755, 0.780, 0.793, and 0.792. The ones for B150 were 0.404, 0.440, 0.516, and 0.506. From the three cases in all, the proposed method shows best score among them so we found that the proposed method gives best scores.

VIII. DISCUSSION

As described in section 5.3, the correlation coefficients showing the consistency of evaluation by expert pianists are found to have no differences. The correlation coefficients for automatic estimation for B150, however, are found to be lower than others, as shown in Figure 9. One of the grounds of the result is that the evaluation parameters could not capture the feature of piano performance for B150 well. Therefore, we need to think of new parameters for task B.

For Top 15 in the correlation coefficient between estimation score employed each parameter and evaluation score given by expert pianists in section 5.2, these parameters are composed by 5 parameters for onset, 4 parameters for duration, and 6 parameters for tempo. Also, they are composed 6 parameters for constant standard, 5 parameters for gradual standard, and 4 parameters for normalized standard. Therefore, Top 15 parameters are composed by comparable parameters for each feature. For A150, B75, and B150, the estimation accuracy for Top 15 is higher than the one for Akinaga(2006). It is thought that the newly proposed standards and parameters are useful on estimation. However, for A75, the estimate accuracy for Top 15 is not higher than the one for Akinaga(2006). We need to discover the root of this result.

IX. CONCLUSIONS

This results show that the proposed parameters concerning moderate performance and constant tendency effectively estimate proficiency. The evaluation parameters representing the individual aspects of the task are confirmed to estimate proficiency of piano etudes effectively, clarifying how artistic deviation affects proficiency evaluation.

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