Quantitative motion analysis of the Japanese folk dance “Hitoichi Bon Odori”

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Bon Odori is a Japanese folk dance performed during the annual Buddhist festival called O-Bon. Hitoichi Bon Odori is known as one of the top three Bon Odori dances in Akita Prefecture. In this study, we present a trial to investigate the motion characteristics of Hitoichi Bon Odori through quantitative motion-capture data analysis. The characteristics of rhythmic style and posture variation are extracted in the analysis. The extracted characteristics were compared with those of the other members of the top three Bon Odori dances, i.e. Kemanai Bon Odori and Nishimonai Bon Odori. The most striking feature of Hitoichi Bon Odori shown in the obtained results was its large expanse of motion characteristics. It was quantitatively confirmed that the expanse was much larger than those of the other dances in both of rhythmic style and posture variation. This tendency was consistent with the oral traditions of the three dances.

1. Introduction

Bon Odori is a Japanese folk dance performed during the annual Buddhist festival called O-Bon. Hitoichi Bon Odori is known as one of the top three Bon Odori dances in Akita Prefecture [1]. The remaining two are Kemanai Bon Odori and Nishimonai Bon Odori. Among these dances, only Hitoichi Bon Odori is classified into the category Odori Nenbutsu (invocations to the Buddha, performed while dancing), whereas the remaining two into Nenbutsu Odori (dances accompanying the recital of Buddhist chants) [1]. Besides, these three belong to the different groups distinguished by geographical location as will be mentioned later. Such differences are thought to have produced the motion characteristics peculiar to Hitoichi Bon Odori [1].

So far, the motion characteristics of Hitoichi Bon Odori have been investigated mainly through qualitative procedures such as researchers’ observations, hearing surveys or literature searches [1][2]. In this study, we adopt the approach of motion-capture (Mocap) data analysis. This allows us to evaluate motion characteristics more objectively and quantitatively, and thereby understand the position of Hitoichi Bon Odori among the folk dances of Akita Prefecture more deeply.

To make it easier to grasp the aspect of dance motion, we separate the process of motion analysis into two parts: the extraction of time-domain characteristics (rhythmic style) and that of spatial-variation characteristics (posture variation). We compare the characteristics extracted from Hitoichi Bon Odori with those of Kemanai Bon Odori and Nishimonai Bon Odori.

2. Bon Odori of Akita Prefecture

2.1 Distribution of Bon Odori dances in Akita Prefecture

The Bon Odori dances of Akita Prefecture are largely classified into three groups distinguished by geographical location: Coastal Area Group (CA), Yoneshiro River System Group (YRS) and Omono River System Group (ORS) [2].

The distribution of the top three Bon Odori dances is shown in Figure 1. Hitoichi Bon Odori is regarded as one of the members of CA, since its home ground, namely the Hitoichi district of Hachirogata Town, exists in the coastal area. Dances belonging to CA are often categorized as the Dagujigu type [1] (Dagujigu: an onomatopoeia describing drum beats, presumed to represent dynamic movements). On the other hand, Kemanai Bon Odori is regarded as belonging to YRS, due to the fact that the Kemanai district of Kazuno City is adjacent to Kosaka River which is a tributary of Yoneshiro River. As for Nishimonai Bon Odori, it is regarded as belonging to ORS, since Nishimonai River flowing near the venue of the O-Bon festival in Ugo Town is part of Omono River System.

The Mocap data of the top three Bon Odori dances
analyzed in this study are shown in Table 1. Multiple data streams are prepared at every dance. The following three sections will give overviews about the features of these dances.

### 2.2 Overview of Hitoichi Bon Odori

Although there is a legend that Ennin (794-864, a priest of the Tendai school) established Hitoichi Bon Odori [3], its origin is in fact uncertain. According to Masumi Sugae’s work [4], however, it is highly possible that the archetype of Hitoichi Bon Odori existed at least in the early nineteenth century, namely in the Edo period.

It is said that a variety of motion styles in the choreography of Hitoichi Bon Odori were gradually organized into two dances, i.e. Dendenzuku Odori and Kitasaka Odori [5]. These dances are known as those with a dynamic quick tempo [1], and their vigorous movements are considered to be comparable to those of Native American dances [5]. As suggested in [1], this property, i.e. the property of Dagujigu seen in CA, may be attributed to the fact that the Hitoichi district belonged to the coastal-area territory of the Hiyama Andō clan (one of the military clans in medieval Japan, having several key ports for the suigun navy) [1].

It has been passed down, on the other hand, that Sankatsu Odori having a graceful slow tempo was later introduced from outside [1]. The origin of Sankatsu Odori is also not known exactly, but one theory states that it may have come from the old capital city of Kyoto [5]. This theory, i.e. the theory suggesting the connection with elegant Kyoto-style culture, well explains the reason why the rhythmic style of Sankatsu Odori is so graceful.

Figure 2 shows the choreography of Hitoichi Bon

### Table 1 Motion capture data of Bon Odori dances.

<table>
<thead>
<tr>
<th>Dance</th>
<th>Index</th>
<th>No. of frames</th>
<th>Dancer</th>
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<tr>
<td>Hitoichi Bon Odori</td>
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</tr>
<tr>
<td>Nenbutsu</td>
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<td>A</td>
</tr>
<tr>
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<td>B</td>
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<tr>
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<td>Odori</td>
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<tr>
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</table>

Frame rate: 30 fps
Motion capture: Magnetic-sensor systems
Hitoichi: MotionStar Wireless (Ascension Technology Corporation)
Kemonai and Nishimonai: MotionStar Wireless with LI-BERTY (Polhemus) × 2

Dancers
A: Female (with more than ten years’ experience in dancing Hitoichi Bon Odori)
B: Female (with more than ten years’ experience in dancing Kemonai Bon Odori)
C: Female (with more than ten years’ experience in dancing Nishimonai Bon Odori)
D: Female (with more than ten years’ experience in dancing Nishimonai Bon Odori)

Odori. The keyposes shown in this figure are the ones selected based on the explanation about the motion sequences of this dance in [1]; we gave one keypose to each unit gesture. It is indicated that the IQR values of keypose intervals are much smaller than the medians of them in all the dances*1. This means that

*1 We use quartiles as the statistics characterizing the distribution of keypose intervals, instead of means and standard deviations. In the case that intervals are grouped into two values, for example, the mean value becomes a value which does not exist in the actual interval values. When the total number of intervals is an odd number, this can be avoided by using the second quartile, i.e. the median. In the case that the total number of intervals is an even number, we supplement a series of interval values with a minimum interval to make the total number an odd number. We selected a minimum interval as a supplement value since more detailed movements can be reconstructed by using shorter keypose intervals.
each dance gives a series of keyposes arranged at substantially regular intervals. As for the medians, on the other hand, values smaller than those of the other dances are given as a whole, as will be shown later.

It can also be recognized in Figure 2 that both the upper and lower parts of the body move relatively vigorously in Dendenzuku Odori and Kitasaka Odori, whereas the lower part is kept motionless throughout the former half of Sankatsu Odori. The latter property, i.e. making gestures while standing with an elegant posture, is considered as one of the causes of the gracefulness seen in Sankatsu Odori [1].

As mentioned in Section 1, Hitoichi Bon Odori is classified into Odori Nenbutsu. The original format of Odori Nenbutsu is that dancers themselves invoke the name of the Buddha (i.e., chant the nenbutsu) while dancing [6]. Although the phrases chanted by the dancers of Hitoichi Bon Odori have little to do with the nenbutsu at the present time [1], the format that dancers vocalize while dancing has been inherited from generation to generation. This has given dancers the pleasure of dancing while calling out to each other, and thereby made Hitoichi Bon Odori “Odoru Odori” (dances recommended to be danced by all the people attending the O-Bon Festival) rather than “Miru Odori” (dances to be appreciated) [1].

The festival of Hitoichi Bon Odori is held in Hachirogata Town on August 18-20.

2.3 Overview of Kemanai Bon Odori

The origin of Kemanai Bon Odori (consisting of Dainosaka Odori and Jinku Odori) is uncertain, same as the case of Hitoichi Bon Odori. However, the connection with the Nenbutsu Odori of Kyoto has been pointed out [2][6][7]. In the performance of Nenbutsu Odori, unlike Odori Nenbutsu, dancers and chanters (or accompanists) are separated from each other [6]; Kemanai Bon Odori is in fact performed in this style. The choreography of Kemanai Bon Odori is often characterized by elegance and refinement [7]. This may suggest the influence of elegant Kyoto-style culture. Due to its simple but sophisticated motion sequences which also give the feel of Kyoto-style culture, Kemanai Bon Odori is regarded as “Miru Odori” rather than “Odoru Odori” [1].

Figure 3 shows the choreography of Kemanai Bon Odori. The keyposes in this figure are the ones used in [7] for illustrating the details of the choreography. It is shown that the IQR values of keypose intervals are much smaller than the medians of them. This means that intervals between keyposes are almost regular in both of Dainosaka Odori and Jinku Odori. It is also recognized that the values of medians are longer than those of Hitoichi Bon Odori. Longer between-keypose intervals can bring gentle transitions between postures, and thereby the elegant and refined impression may be produced.

As mentioned in Section 2.1, Kemanai Bon Odori belongs to YRS. According to [2], the folk performing arts belonging to YRS are marked by large-sized drums used in musical performances. On the other hand, however, no distinctive motion characteristic symbolizing the choreography of the dances belonging to YRS has been reported up to the present.
Therefore, the characteristics mentioned above may be limited to the case of Kemanai Bon Odori. The festival of Kemanai Bon Odori is held in Kazuno City on August 21-23.

2.4 Overview of Nishimonai Bon Odori

As for Nishimonai Bon Odori (consisting of Ondo and Ganke), there are several oral traditions about its origin. A typical one is that the vassals of the Onodera clan (ruined after the Battle of Sekigahara in 1600) started it to pray for the dead soul of their feudal lord [8][9]. It is said that at that time one of the Hönen Odori dances, established in the thirteenth century by a monk named Genshin, was incorporated [8][9]. According to [8], this dance was originated from the drama style Ennen including a variety of elaborate performance forms [6]. In fact, the motion sequences of Nishimonai Bon Odori consist of a relatively long series of various sophisticated movements: e.g., graceful arm movements suggestive of a rice ear waving in the wind [8], etc. This tendency, i.e. elaborate motion sequences, is often seen in the dances belonging to ORS [10].

The above motion feature is extremely fascinating, and recently it is becoming an important factor to attract tourists [11]. Due to this situation, many people recognize Nishimonai Bon Odori as “Miru Odori” [1][11]. As mentioned in Section 1, on the other hand, Nishimonai Bon Odori is also classified into Nenbutsu Odori because of its performance style, i.e. separation between dancers and chanters [1].

Figure 4 shows the choreography of Nishimonai Bon Odori. The keypoints in this figure are the ones used in [12] for illustrating the details of the choreography. The number of keypoints in Ondo is 25 and that in Ganke 29 (both consist of two verses*2). These numbers are much larger than those of Hitoiichi Bon Odori and Kemanai Bon Odori (i.e. the numbers less

*2 Two verses have almost the same length in both of Ondo and Ganke. In Section 4, an entire motion sequence including both of two verses is analyzed as one dance.
than or equal to 12). In addition, the IQR value of
keypose intervals in Ganke is considerably large
compared with those of the other dances, although
that in Onodo is almost zero. These data indicate
the elaborateness of the choreography of Nishimonai Bon
Odori. It is also shown that the values of medians,
especially that of Onodo, are longer than those of Hi-toichi Bon Odori.

The festival of Nishimonai Bon Odori is held in
Ugo Town on August 16-18.

3. Analysis Methods

3.1 Comparison of motion characteristics

As mentioned in Section 2, the dances analyzed in
this study have a variety of motion styles. To enable
the comparison of motion characteristics among such
dances, extracting motion characteristics in a unified
format is desirable. As for both of rhythmic style and
posture variation, fortunately, relatively simple analysis
methods providing motion-characteristic data in
a unified format were already proposed [13][14]. We
adopt these methods as follows.

3.2 Extraction of rhythmic-style characteristics

To extract the rhythmic-style characteristics
of each dance, we use a modified version of the method
proposed in [13]. The degree of beat intensity and
that of rhythm complexity is evaluated in this method.

First, we obtain a one-dimensional motion-speed
time series from the displacement of J = 16 points
(shoulders, elbows, wrists, fingers, knees, ankles, toes,
neck and head):

\[ v(n) = \frac{\sqrt{\sum_{j=1}^{J} \sum_{\gamma=x,y,z} \left( p_{j,\gamma}(n) - p_{j,\gamma}(n+1) \right)^2}}{\Delta t} \]  

(1)

where \( p_{j,\gamma}(n) \) (\( \gamma: x, y \) or \( z \)) is the \( \gamma \)-coordinate of the
\( j \)th point at the \( n \)th frame (coordinate system: fixed to
the pelvis) and \( \Delta t \) the sampling time (\( \Delta t = 0.033 \) sec),
respectively. The values of \( p_{j,\gamma}(n) \)’s are filtered to
eliminate jitter (by using a Gaussian filter, cut-off
frequency: 9.0 Hz), and normalized by the height of
the body to reduce the influence of difference in body
constitution.

By using the above time series, we estimate the
degree of beat intensity (BI) as follows:

\[ \text{BI} = \frac{1}{2} \log \left( \frac{\sum_{n=1}^{N} \left| v(n) - v_{m}(n) \right|^2}{N} \right) - A \log(\tau \Delta t) \]  

(2)

where \( \tau \) is the frame number giving the first positive
peak of the autocorrelation of \( v(n) \) (regarded as the
beat interval), \( v_{m}(n) \) the moving average of \( v(n) \) (pe-
period: \( \tau \)), \( N \) the total number of frames and \( A \) the
weighting coefficient to the beat-interval element \( \tau \Delta t \),
respectively. We obtained Eq. (2) by applying a loga-

rithm transformation to Eq. (2) of [13]. This modification allows us to adjust the weighting ratio between
the speed-variation element (the first term of (2)) and
the beat-interval element (the second term of (2)); we
finally set \( A = 0.2 \). The larger the speed variation in
each beat interval is, or the quicker the beat appear-
ance is, the larger the value of BI becomes.

As for rhythm complexity, on the other hand, the
value of approximate entropy (ApEn) [15][16] ob-
tained from \( v(n) \) is used [13]:

\[ x(n) = [v(n) \ v(n+\tau) \ \ldots \ v(n+(m-1)\tau)]^{T} \]

\[ d(x(n), x(j)) = \max \{ |v(n+k-1)\tau - v(j+k-1)\tau)| \} \]

\[ C_{\tau}^{n} = \frac{\sum_{j=1}^{N-(m-1)\tau} \theta(r - d(x(n), x(j)))}{N - (m-1)\tau} \]

\[ \Phi^{n} = \frac{\sum_{\tau=1}^{N-(m-1)\tau} \log C_{\tau}^{n}}{N - (m-1)\tau} \]

\[ \text{ApEn} = \Phi^{n} - \Phi^{n+1} \]  

(3)

where \( \tau' = \text{INT}(0.2r) \), \( m = 3 \), \( r = 0.25 \times \) (standard devi-
ation of \( v(n) \)) and \( \theta(x) \) is the Heaviside function, re-
respectively. Equation (3) represents the ApEn model
including the time-delay parameter \( \tau' \) [16]. We adopt
this model since the time scale of autocorrelation in
Mocap data is generally much longer than \( \Delta t \). The
ApEn value becomes large when the variation of motion
speed shows a large amount of complexity.

3.3 Extraction of posture-variation characteristics

As for the extraction of posture-variation character-
istics, we use the method proposed in [14]. This method
statistically summarizes the spatial distribution of
the 16 points used in Eq. (1) as a 12-dimensional
feature vector.

First, the distribution of the above points is quanti-
fied at each frame using the variances and cova-
iances of coordinate values:

\[ \bar{p}_{\gamma}(n) = \frac{1}{J} \sum_{j=1}^{J} p_{j,\gamma}(n) \quad (\gamma: x, y \text{ or } z) \]

\[ \sigma_{\gamma}(n) = \frac{1}{J} \sum_{j=1}^{J} \{ p_{j,\gamma}(n) - \bar{p}_{\gamma}(n) \} \{ p_{j,\gamma}(n) - \bar{p}_{\gamma}(n) \} \]

(4)

As shown in Figure 5, a set of six values obtained
from Eq. (4) represents the dispersion along the three
axes of movement (frontal, vertical and sagittal axes)
and that on the three planes of movement (frontal,
sagittal and horizontal planes). We treat these values
as the components of the feature vector $f(n)$ characterizing a posture in each frame:

$$f(n) = \begin{bmatrix} f_1(n) & f_2(n) & f_3(n) \\ f_4(n) & f_5(n) & f_6(n) \end{bmatrix} = \begin{bmatrix} \sigma_{xx}(n) & \sigma_{xy}(n) & \sigma_{xz}(n) \\ \sigma_{yx}(n) & \sigma_{yy}(n) & \sigma_{yz}(n) \\ \sigma_{zx}(n) & \sigma_{zy}(n) & \sigma_{zz}(n) \end{bmatrix}$$ (5)

Finally, the tendency throughout an entire motion sequence is statistically summarized as the 12-dimensional feature vector $F$ as follows:

$$\bar{f_i} = \frac{1}{N} \sum_{n=1}^{N} f_i(n) \quad (= \sigma_{qq\text{mean}})$$

$$\tilde{s}_i = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (f_i(n) - \bar{f}_i)^2} \quad (= \sigma_{qq\text{SD}})$$

$$F = \begin{bmatrix} \bar{f}_1 & \bar{f}_2 & \cdots & \bar{f}_8 & \tilde{s}_1 & \tilde{s}_2 & \cdots & \tilde{s}_8 \end{bmatrix} = \begin{bmatrix} \sigma_{xx\text{mean}} & \cdots & \sigma_{xx\text{mean}} & \sigma_{xx\text{SD}} & \cdots & \sigma_{xx\text{SD}} \end{bmatrix}$$ (6)

The former six components represent the dispersion averaged throughout an entire motion sequence. Three of them correspond to the dispersion along the three axes of movement, whereas the remaining three to the dispersion on the three planes of movement. On the other hand, the latter six components represent the fluctuation of dispersion during an entire motion sequence. These six components also correspond to the axes and planes of movement respectively.

4. Results and Discussion

4.1 Rhythmic-style characteristics

The distribution of the rhythmic-style characteristics of all the Mocap data in Table 1 is shown in Figure 6. The top three Bon Odori dances formed their respective clusters. The within-cluster variances of these dances are shown in Table 2. From these data, one can recognize that the cluster of Hitoichi Bon Odori spread more widely than those of Kemanai Bon Odori and Nishimonai Bon Odori. In particular, the spread in a horizontal direction, i.e., the variety of beat intensity, was remarkable. As mentioned in Section 2.2, Hitoichi Bon Odori had originally consisted of two quick-tempo dances (Dendenzuku Odori and Kita-Jindai) and Sankatsu Odori having a graceful slow tempo was later introduced from outside. The obtained results are consistent with this oral tradition.

As for rhythm complexity, Hitoichi Bon Odori was located at the area of “Simple.” Its simplicity was much higher than that of Nishimonai Bon Odori well known for its sophisticated movements. As already described in Section 2.2, Hitoichi Bon Odori has been regarded as “Odoru Odori” rather than “Miru Odori.” This may have brought a simple rhythmic style everyone can easily dance.

It is also shown that Sankatsu Odori was located at the area close to that of Kemanai Bon Odori. This suggests that these dances might have some property common to both of them. As mentioned in Sections 2.2 and 2.3, it has been pointed out that both of Sankatsu Odori and Kemanai Bon Odori show the possi-
bility of having the connection with Kyoto-style culture. The obtained results could support this theory.

### 4.2 Posture-variation characteristics

To grasp the distribution of posture-variation characteristics in a low dimensional space, i.e. on a plane, we applied factor analysis to the set of the feature vectors obtained from all the Mocap data in Table 1. These data were analyzed by the principal factor method with the normal varimax rotation for an $l = 2$ factor model ($l$: number of common factors) [17]. The obtained result is shown in Table 3. Although the number of common factors was only two, the total contribution of them greatly exceeded 50%. The first factor is regarded as corresponding to transverse motion since it is dominated mainly by $\sigma_{xx}$, $\sigma_{yz}$, and $\sigma_{zy}$; all of them include the $x$ component corresponding to a transverse direction. On the other hand, the second factor, dominated mainly by $\sigma_{xz}$, $\sigma_{xy}$, and $\sigma_{yz}$, can be interpreted as that representing the direction of dispersion on the sagittal plane corresponding to the $yz$ plane.

The distribution of posture variation, obtained from the factor scores of all the Mocap data, is shown in Figure 7, and the within-cluster variance of each dance is shown in Table 4. In Figure 7, the cluster of Hitoichi Bon Odori was separated into two parts in a vertical direction, i.e. distinguished by the aspect of posture variation on the sagittal plane. The cluster of Nishimonai Bon Odori was put between them. The within-cluster variance of Hitoichi Bon Odori thereby increased as shown in Table 4.

As mentioned in Section 2.2, the lower part of the body is kept motionless in the former half of Sankatsu Odori. During this period, the right foot is raised in a forward-downward direction on the sagittal plane, and at the same time the arms are gently moved. The gracefulfulness of Sankatsu Odori remarkably appears in this situation. In Dendenzuku Odori and Kitasaka Odori, on the other hand, the arms are vigorously raised in a forward-upward direction as shown in Figure 2. This movement can be considered as contributing to the enhancement of the Dagujigu property. Such a contrast between Sankatsu Odori and the remaining two is quantitatively reflected in the separation of the cluster shown in Figure 7.

As for the factor of transverse motion, on the other hand, the distinctiveness of Kemanai Bon Odori was rather emphasized than that of Hitoichi Bon Odori. In fact, the action of reaching out an arm in a transverse direction, shown in Figure 3, is a distinctive motion in Kemanai Bon Odori. As pointed out in Section 4.1, the rhythmic-style characteristics of Kemanai Bon Odori were considerably close to those of Sankatsu Odori. Nevertheless, Kemanai Bon Odori showed extremely different posture-variation characteristics from those of Sankatsu Odori. This means that the property common to both of them would be unassociated with any spatial aspect of dance motion.

### 4.3 Discussion

The most striking feature of Hitoichi Bon Odori shown in the above results is its large expanse of mo-
tion characteristics. It was confirmed that the expanse was much larger than those of Kemanai Bon Odori and Nishimonai Bon Odori in both of rhythmic style and posture variation.

The above feature may be attributed to the fact that Hitoichi Bon Odori is regarded as “Odoru Odori” (originated from the format of Odori Nenbutsu as mentioned in Section 2.2). In old times, according to [1], people who came to the Hitoichi district from other places attended the O-Bon festival, and performed the dances inherited in their own hometowns. Even people from other places were allowed to dance freely because Bon Odori had been recognized as “Odoru Odori” there. Such a custom is thought to have led to the introduction of new dance styles from outside. This kind of oral tradition, i.e. introducing dance styles later from outside, is not seen in both of Kemanai Bon Odori and Nishimonai Bon Odori. It seems to be reasonable to think, therefore, that this situation was at least one of the factors which caused the expanse of motion characteristics only for Hitoichi Bon Odori.

The above tendency was quantitatively clarified by analyzing Mocap data. This suggests that the introduction of Mocap data analysis into the investigation of folk dances is really effective.

5. Conclusions

The main contribution of this study is the introduction of Mocap data analysis into the investigation of the folk dance Hitoichi Bon Odori. The proposed approach gave a successful outcome that motion characteristics peculiar to Hitoichi Bon Odori were quantitatively clarified. The next step would be to increase the number of dances used in the analysis. It is expected that the obtained results will further expand our knowledge about the folk performing arts of Akita Prefecture.

References


*3 There were many visitors to the Hitoichi district which had prospered since the early Edo period as a post town.