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Automatic Generation of Dancing Motion for the Computer Controlled Automata Based on the Dancing Rules

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Abstract: In this paper, we propose a method by which dancing motions can be generated automatically using various dancing rules. Hence the burdensome task of teaching can be avoided by using our proposed method. We have analyzed the dancing motions taught by an expert dancer to the automata and have extracted the dancing rules. The size and the direction of the motion of each degree of freedom are generated according to these dancing rules. Additionally, the timing of the dancing motions of each degree of freedom is decided according to the timing and the length of note acquired from the music.

Keyword: Automata, Dancing Motions, Automatic Generation

1. Introduction

Robots nowadays can be classified roughly as an industrial robot and non-industrial robots. Amusement Robots are non-industrial robots which can amuse a person by their Gestures and Motions, etc. Awa Odori robots by Fujiwara et al.[1] and Pets robot by SONY[2] are some of the amusement robots reported in Japan. Presently many researchers are doing active research in this field.

Classical automata and Karakuri-ningyo are included into the category of amusement robots. Their motions are generated by the mechanism of gears, cams, levers and links and always depend on the type of mechanism they have. Their motions are fixed and repeatable. Different motions are not possible without changing their mechanism. On the other hand, Computer Controlled Automaton (CCA) was developed in recent years [3]. The CCA is the amusement robot that can perform various dancing motions by controlling the servomotor that drives each joint using computer. In the CCA, the robot is operated directly using a joystick and a human operator has to teach robot various dancing motions in real-time by using the joystick. A human operator listens to the music and moves the CCA in real-time using the joystick to generate a dancing motion. The data of the dancing motion stores into the computer memory. In the CCA, it is possible to generate various dancing motions. There are two problem associated with this approach. First a human operator has to familiarize with such kind of manual control, which requires lot of practice time. Secondly, to generate such kind of motions, the dancing expertise of the teaching person is required. Hence generation of a single satisfactory dancing motion consumes lot of time that limits the possibility of teaching various dancing motions to the CCA. In our proposed method, we have used the motion data taught by an expert dancer to extract the dancing rules for the CCA related to various basic notes of the music. In this way, we can reduce the burden of teaching various dancing motions to the CCA by an expert dancer. Timing of the dancing motion is adjusted according to the timing of the music that can be done easily by analyzing the MIDI file of the music. The timing and length of each musical note can be extracted from the MIDI file and can be used to decide the timing and length of the motion of each degree of freedom of doll. These dancing motions then can be visualized on the computer graphic screen to verify the beauty and smoothness of the motions.

2. Real-time instruction method

The flow diagram of the generation of a dancing motion by the CCA is shown in Figure 1. A human operator listens to the music and imagines a dancing motion that can be appropriate with this music. For a particular dancing motion, he tries to decompose this motion into individual motions for each degree of freedom of the CCA. Once he decided about the individual motions of each degree of freedom of the CCA and their sequence, he tries to move each part sequentially in real-time to mimic the motions of each part that he has in mind. All motion data is stored in the computer and can be played back to see the motion that he has generated using the joystick. In the repetitive process he can evaluate and correct the motion until he is satisfied. Once he finishes with the motions of all degree of freedoms, he can visualize complete dancing motion of the CCA on the computer screen. He can modify the dancing motion to his satisfaction in the repetitive process of correction and watching. Once he is satisfied with the motion of all DOFs, a dancing motion is complete. Generation of a satisfactory dancing motion by this way requires great amount of time and training especially when the human operator is not well trained and does not have enough expertise in dance.

The most difficult part of the above method is to visualize a dancing motion and to decompose that dancing motion into motions of each DOF of the CCA. The clear difference between the performances of a person having dance expertise and a person without any dance expertise is reported in [4].

3. Generation of dancing motions

It is important to know the formation of music data file to extract the timing and length of music, which is

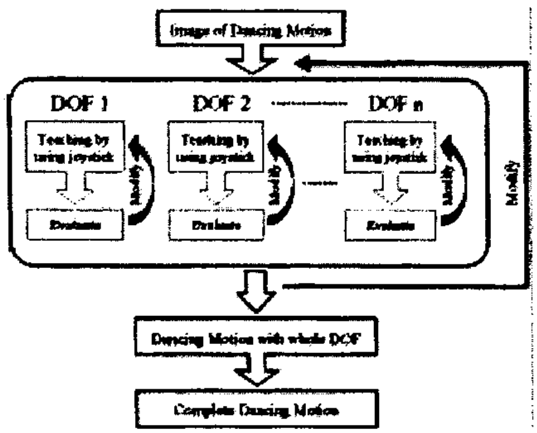

Fig. 1 Generation of a dancing motion

important in synchronizing the CCA motion with music. In order to analyze the music information on computer, we have used MIDI file format. MIDI (Musical Instrument Digital Interface) is an interface that converts the music generated by musical instrument into standard digital format [5]. The MIDI protocol describes the entire music in binary form. Each word describing an action of musical performance is assigned a specific binary code. The binary data of MIDI can be analyzed easily to retrieve the information about the musical note length, volume etc.

Figure 2 shows a part of the motion data of the CCA describing the variation of angle and angular velocity of one DOF of the CCA. It shows the relationship between the rhythm and the dancing motion. From the MIDI file, the events of note On and Note Off are used to control the motion of the CCA. When music starts, the CCA motion starts simultaneously and when music stops, the CCA also stops simultaneously. While there is no music, the joint angle remains on the same position as before and will start to move only when sound starts. Hence the motion of the CCA is synchronized with the timings of starting and stopping of the note.

Once the angles of each DOF are known, let Θ_n, Θ_{n+1} are the angles of motion for start and end of one music note. For the next music note, the angle Θ_{n+1} will

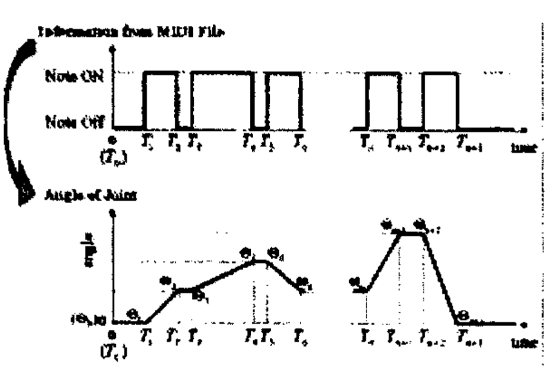

Fig. 2 Motion Data of CCA with rhythm

become the start angle for the next motion and Θ_{n+2} will be the angle for the end of second note and vice versa. For the smooth transition of angle of joint from the starting angle Θ_n to ending angle Θ_{n+1}, we have used trigonometric function to interpolate the angle between the time interval when music starts and ends. Let the time of the start of music is T_n and time of end of music is T_{n+1}. The angle transition $\theta(t)$ from Θ_n to Θ_{n+1} is given below,

$$\theta(t) = \Theta_n + \frac{\Theta_{n+1} - \Theta_n}{2}\left\{1 - \cos\left(\frac{t - T_n}{T_{n+1} - T_n}\pi\right)\right\} \tag{1}$$

The angular velocity is,

$$\dot{\theta}(t) = \frac{\Theta_{n+1} - \Theta_n}{2} \cdot \frac{\pi}{T_{n+1} - T_n} \sin\left(\frac{t - T_n}{T_{n+1} - T_n}\pi\right) \tag{2}$$

The angular velocity at the terminals of the time interval ($t = T_n$, $t = T_{n+1}$) will be zero to maintain the continuity in the angular velocity pattern. Hence the angular velocity for one complete tune will be continuous.

4. Formation of dancing motion rule

Generating the dancing motions for a CCA having many DOFs synchronized with the rhythm of music is a complicated task. In this paper, our emphasis is to extract some basic motions or rules that governs the overall dancing motions of a dancer.

4.1 Extraction of dancing motion rule

In the section, method of extraction of the dancing rule from the dancing motion data taught by an expert dancer is explained.

In the start, the dancing motion data that is taught by an expert ballet dancer to the CCA is analyzed. Our aim is to generate the dancing motions for the CCA using some basic dancing motion rules for ballet dance music. During the dancing motion of the CCA, motion of every joint can be expressed as a combination of many basic motions. When we analyze the motion data, we find that most of the time all joints do not move simultaneously. Motion of some joints is significant than others on certain times and vice versa. Hence to form a dancing motion, it is important to know that which joint moves when and what is the order of motion. Based on these observations, three indices are defined: The domination of joints motion, synchronization of the motion and the correlation between joints motions.

■ **Domination Ratio**

It is an index that gives the ratio of the motion of a particular joint during the whole time span of a certain music note. The index is described below,

$$D_j = \frac{\sum_{i=0}^{N-1} n_j^i}{N} \tag{3}$$

Here n_j^i describes the motion of joint in time and will be equal to 1 when the joint is moving and 0 when joint is not moving. N is the number time steps in one musical note. Hence this index will have large value for the joint, which is moving more frequently showing the significance of the joint in the dancing motion.

■ **Synchronization Ratio**

It is the index, which displays the ratio of time when two joints i and j are in motion simultaneously and the time when either of them is in motion. The following relation describes the index,

$$S_{i,j} = \sum_{t=0}^{N-1} \left(n_i^t \cdot n_j^t\right) \Big/ \sum_{t=0}^{N-1} \left(n_i^t + n_j^t\right) \tag{4}$$

Where " · " represents a logical "AND" and " + " represents a logical "OR". Higher value of index indicates the synchronization of two joints motion.

■ **Chain Ratio**

In a certain one music note, when the joint angular velocity returns to zero, we consider it as a single motion. In addition, it arranges the motion of all joints in the time series. It sets the time section T_k ($k = 0,1,2,\cdots K$) for the combined motions. It is the index of chain ratio of all motions of joint j when the joint i was in motion one time section before the motion of joint j. The index is given as,

$$C_{i,j} = \sum_{k=0}^{K} \left(n_i^{T_{k-1}} \cdot n_j^{T_k}\right) \Big/ \sum_{k=0}^{K} n_j^{T_k} \tag{5}$$

Where "·" represents a logical "AND". $n_j^{T_k}$ represents the motion of joint j in the time section T_k. It will be equal to 1 when joint is in motion and will be 0 when joint is stopped. Higher value of the index shows that the motion of joint i followed by the motion of joint j is happening more frequently.

The above three indices are given in Table 1~3 for dancing motions taught by an expert dancer.

We can verify following kind of features from the Tables,

- Arm and revolution joints moves more frequently.
- Motion of both arm joints is more frequent in the same time period.
- Both arms and waist joints moves in alternate more often (refer to the $C_{i,j}$ of arms and waist).

Table 1: Domination Ratio for the Music "March"

j	0	1	2	3	4
D_j	0.45	0.17	0.19	0.69	0.45

Table 2: Synchronization Ratio for the Music "March"

i \ j	0	1	2	3	4
0		0.28	0.12	0.38	0.28
1	—		0	0.23	0.36
2	—	—		0.12	0.03
3	—	—	—		0.50
4	—	—	—	—	

Table 3: Chain Ratio for the Music "March"

i \ j	0	1	2	3	4
0	0.30	0.17	0.43	0.22	0.22
1	0.50	0.90	0	1.0	1.0
2	0.17	0	0.70	0.17	0.13
3	0.16	0.20	0.02	0.77	0.59
4	0.15	0.18	0.04	0.47	0.84

Hence we can extract some rules for dancing motion based on above indices. We can decide the combination and order of the motions of joints according to these rules.

Next, size of motion of the joint and extraction of the rule, which decides direction, are done. Here other than looking at the movement of the joint angle in the motion data taught by expert dancer, the CCA was moved in real-time and features of motion were extracted by observing the motions. The features, which are obtained, are listed below,

- The size of motion of a joint in a single time step is almost fixed.
- Arms and waist joints move frequently in forward and backward directions.

By utilizing these features, we can decide the motion of joint angles within the movable and angular velocity limits.

4.2 Generation of dancing motion by using dancing rules

By using the features as dancing motion rules mentioned in the previous section, it is possible to generate a continuous dancing motion. The dancing motion generation by our proposed technique is shown in Figure 3. Motion decision for a time step is done in two steps. In the first step the working condition of each joint is decided. The function $F_{comb}^m(j)$ gives the working condition of the motion of joint j when motion of joint i and motion of joint j are in the same time. The function $F_{chain}^m(j)$ is defined as the chain of the motion of all joints in the $m-1$ time step when the joint j is in motion. The functions $F_{comb}^m(j)$ and $F_{chain}^m(j)$ are given in equations (6) and (7).

$$F_{comb}^m(j) = P_i^D \cdot P_{T,j}^S + \overline{P_i^D} \cdot P_{F,j}^S \tag{6}$$

$$F_{chain}^m(j) = n_0^{m-1} \cdot P_{0,j}^C + n_1^{m-1} \cdot P_{1,j}^C + n_2^{m-1} \cdot P_{2,j}^C + n_3^{m-1} \cdot P_{3,j}^C + n_4^{m-1} \cdot P_{4,j}^C \tag{7}$$

Where " · " represents a logical "AND" and " + " represents a logical "OR". P_i^D, $P_{T,j}^S$, $P_{F,j}^S$, $P_{i,j}^C$ are the random variables which take the values of 1 and 0 according to certain probability distribution. The probability distributions are defined based on the three indices defined in section 4.1. The variable n_i^m is the state of joint i in m^th^ time where 1 corresponds to moving state of the joint and 0 corresponds to not moving state of the joint. In equation (6), if the joint i become the standard joint during the dance motion, the equation (6) can be replaced by the following equation,

$$F_{comb}^m(j) = P_{base}^D \cdot P_{T,j}^S + \overline{P_{base}^D} \cdot P_{F,j}^S \tag{8}$$

$F^m(j)$ is the function which decides the state of a joint j in the m^th^ time step is given as follows

$$F^m(j) = F_{comb}^m(j) + F_{chain}^m(j) \tag{9}$$

Where "·" represents a logical "AND. If $F^m(j) = 1$, joint j will move and if $F^m(j) = 0$, it will not move. In the next step, motion of the joint is designed. Let the initial angle of joint j at the start of m^th^ time step T_B^m is $A_B^m(j)$ and the final angle of the joint j at the end of m^th^ time step T_E^m, when music stops, is $A_E^m(j)$.

For $F^m(j)=1$, $A_E^m(j)$ will move and change its position. The motion of joint angles will be decided according to the rules mentioned in Table 4. The change of joint angles can be described by the following set of equations,

$$A_E^m(j)=A_B^m(j)+A^m(j) \tag{10}$$

$$A_E^m(j)=A_B^m(j)-A^m(j) \tag{11}$$

Here, it is necessary to consider the angular limit and the angular velocity limit of a particular joint. Let the angular limit of joint in the motion towards forward direction is $A_{MAX}(j)$ and the limit of angular velocity is $V_{MAX}(j)$, the motion of joint angle will follows the following rule,

$$-A_{MAX}(j)\le A_E^m(j)\le A_{MAX}(j) \tag{12}$$

$$A^m(j)\le V_{MAX}(j)\cdot\left(T_E^m-T_B^m\right) \tag{13}$$

From the above rule, the joint angle $A_E^m(j)$ is decided.

Table 4: Rules for the size and direction of angles

	$j=0$	$j=1,2,3,4$
Size	The size $A^m(j)$ is selected from four patterns. $(A_0(j)\cdot A_1(j)\cdot A_2(j)\cdot A_3(j))$	
Direction	If the joint angle is below $\pm$ 60[deg] ,the direction is considered to be facing the subject.	If the angle is at initial position, the direction of next motion will be opposite of the previous motion.
	If the joint angle is more than 60[deg] , the direction of CCA is considered to be facing opposite of the subject.	If the angle is near initial position, the direction of motion will be same previous motion.
		If the angle is far from initial position then the direction will be back towards the initial position.

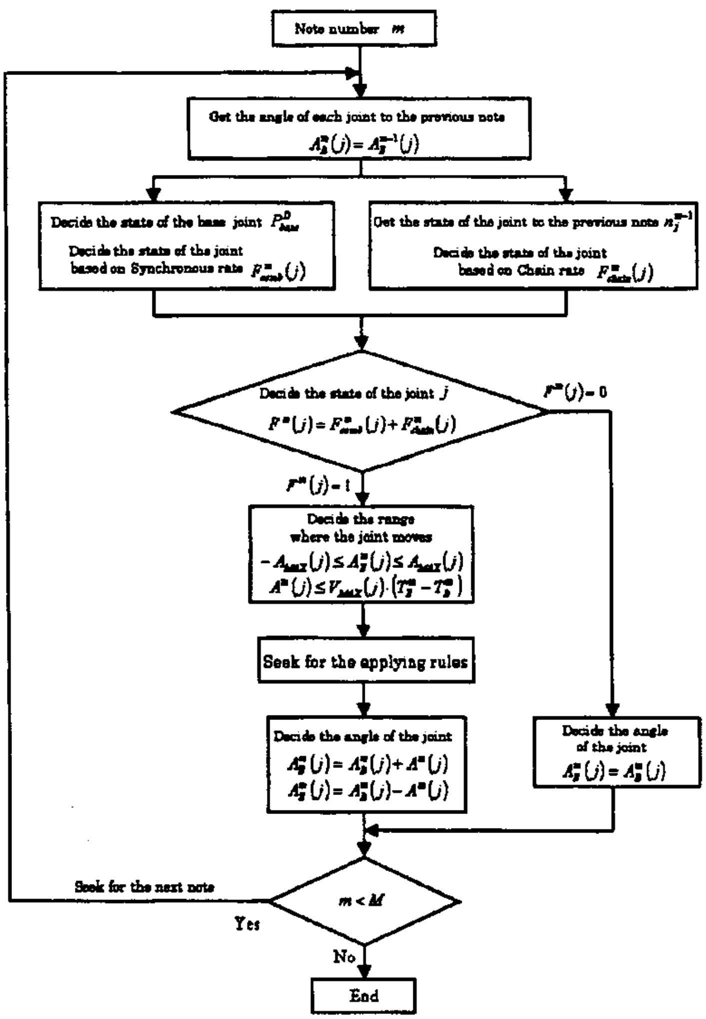

Fig.3 Dancing Motion generation by proposed rules

Table 5: Synchronization Ratio

j	$P[P_{base}^D=1]$	$P[P_{T,j}^S=1]$	$P[P_{F,j}^S=1]$
0	——	0.5	0.2
1	——	0	0.5
2	——	0	0.5
3	——	1	0
4	0.25	1	0

Hence using the information from the music, it can generate the motion of a particular joint following the above mentioned rules.

4.3 Example of dance motion generation

In Figure 4, an example of dance motion generated by our proposed technique is shown. Dancing motion is generated for the same MIDI file of ballet dancer used in the extraction of the rules. In forming the rules, the values of the indices mentioned in section 4.1 were calculated from the dance motion data taught by an expert ballet dancer. First the left arm is set as reference with probability $P_{base}^D=1$ and $P_{T,j}^S=1$ as given in Table 5. Hence when the standard joint moves or stops, the probabilities of motion of joint j will decide the value of $F_{comb}^m(j)$. In the same way, when $P_{i,j}^C=1$, the probabilities are given in Table 6. When the joint moves, the probabilities of joints motion will decide the value of $F_{chain}^m(j)$.

Figure 4 shows the automatic motion generation for the music of "Waltz of Flower". Continuity of motion is visible. Left and right

Table 6 : Chain Ratio

j	$P[P^C_{0,j}=1]$	$P[P^C_{1,j}=1]$	$P[P^C_{2,j}=1]$	$P[P^C_{3,j}=1]$	$P[P^C_{4,j}=1]$
0	0.5	0	0.2	0	0
1	0	0	0	0.2	0.2
2	0.2	0	0.5	0.2	0.2
3	0.2	0	0	0.2	0.5
4	0.2	0	0	0.5	0.2

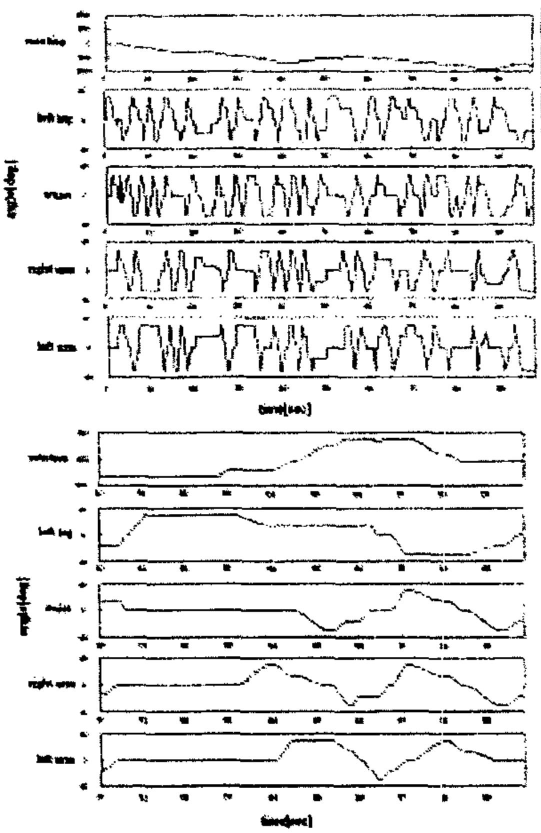

Fig.4 Example of joint angles generated by dancing rules.

arms performing motion in the same time period and arms moves after the motion of waist.

5. Subjective evaluation of motion generation

The dancing motions are generated by the technique mentioned in the previous section. In this section, subjective evaluation of the dancing motioned generated by basic rules is described. The CCA performs the dancing motions on computer screen and a subject watches these motions and evaluates the dancing motion.

Data type 1 is the motion data taught to the CCA by an expert ballet dancer. Other three data types are the motion data generated automatically by dancing motion rules. The difference among the data types 2-4 is the different synchronization ratio. We have used four types of ballet music patterns and four types of basic dancing motion rules. Hence the total numbers of patterns are sixteen. All these motions are shown to the subject randomly on the computer graphic screen. The subjective rating includes Activity, Interest, Beauty, Rhythmical, Affinity and According to music. A subject has to evaluate the dancing motion on a five-point scale. The subjects are ten young students in the age of early twenties. Subjective evaluation results are shown in Figure 5 for four data types. It can be observed from the figure that all the subjects gave high ranking to the dancing motions taught by ballet dancer. But the subjective rating of the four data types are almost equal as far as rhythmical and according to music motions are concern. Hence the generation of dancing motions according to the music is very effective by using our proposed dancing motion rules. The subjective rating is low in the cases of activity, interest and affinity. Hence it is necessary to define further dancing rules that address these impressions.

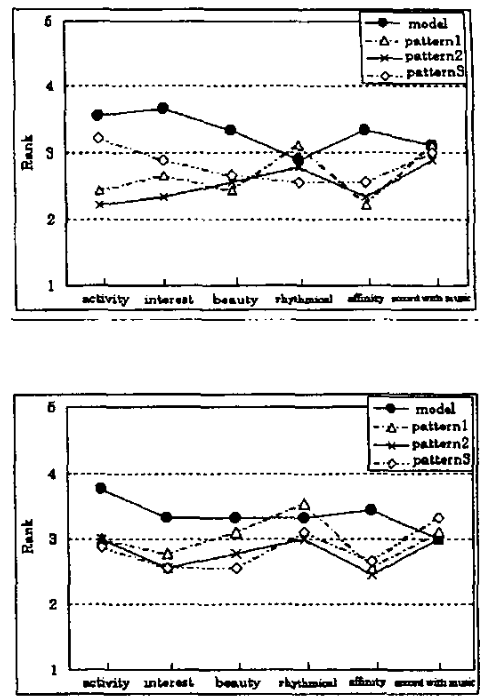

Fig.5 Subjective rating results

6. Conclusions

In this paper, we have extracted some basic dancing motion rules from the dancing motion data taught to the CCA by an expert ballet dancer. These dancing rules are used to generate dancing motions automatically according to the ballet music. In addition, the timing information is extracted from the MIDI file of music and the dancing motion is synchronized with the timing of the music notes.

Subjective evaluation of the dancing motions confirms the effectiveness of our proposed technique. We can achieve good synchronization with the music although the rating for beauty and interest is still low.

The main advantage of this technique is that we can generate various dancing motions automatically in synchronization with the music. In our future work, we will try to create or modify more basic dancing rules to improve the beauty of the dancing motion and to make it more interesting.

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