Teaching of Dancing Motions to Computer Controlled Automata Using Sequential Motions

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In this paper we propose a method to develop the program of continuous dancing motions using discrete motions sequentially for a computer-controlled automaton. Firstly a human listens to music and he imagines dancing motions. Secondly he generates a series of discrete skeleton images on a CRT display using a mouse. The skeleton image is the model of an automaton which has been developed in advance. Thirdly the continuous trajectories are generated by interpolating the sequential dancing images. Finally the continuous dancing motions of the skeleton images are evaluated on a CRT screen with the music. If necessary, the modification is repeated until a satisfactory motion is realized. The final check of the computer program is done by using the real automaton.

KEYWORDS: robot, computer controlled automata, teaching, dancing motion

1. Introduction

Classical automata in European countries and Karakuri-ningyo in Japan were designed for amusement and have been giving enjoyment with their dexterous motions [1]. The motions are generated by the mechanism of gears, cams, levers and links; the power is supplied by a spring. Thus the motions are repeated ones even if the pattern is complicated.

Recently robots are developing in the field of amusement [2]. The technology of mechatronics can realize many different kinds of motions of amusement robots. A computer controlled automaton (CCA) is a kind of small robot designed for amusement [3]. The appearance is shown in Fig. 1 and the mechanism is shown in Fig. 2. It has five degrees of freedom; both arms, the waist, the right leg and the whole body can be moved independently by five servomotors. The servomotors are controlled by a computer program; thus, many dancing motions will be executed only by the change of a program. The computer program for the CCA is quite complicated and it will require a considerable amount of time to develop a satisfactory program. Thus an effective teaching method is expected to develop such a program.

There have been reported many teaching methods for industrial robots [4]. The teaching/playback method is the most popular one. A human operator moves a robot arm manually through some desired points in a work space. The corresponding position data are stored in a computer. This method has its widespread applications in the early industrial robots. Offline teaching, where teaching/playback is conducted and tested using an offline robot, is also used widely. Furthermore, a robot simulator has been developed and used in offline teaching [5]. In these methods, the motion planning focuses on the position and direction of a hand. And the precision of positioning is the most important. In many cases, the velocity pattern between the specified points is not important. In the CCA, however, the velocity patterns along trajectories of all components of the CCA are crucial to realize an impressive dancing motion. In order to meet these requirements, the conventional teaching/playback method was modified and the real-time teaching method has been proposed [6]. This is the simple way of the motion planning; a human operator moves the CCA at real-time using a joystick while listening to music and the position data are stored in a computer. A satisfactory motion will be available if the human is experienced with this kind of manual control and the arrangement of a dance. Even if an experienced operator conducts the real-time teaching, it requires a considerable amount of time to achieve satisfactory dancing motions.

In this paper we examine the real-time teaching method and propose a new method to develop the program of a dancing motion. Firstly the sequential use of discrete motion image is explained. Like the real-time teaching method, a human operator moves the skeleton image of the CCA using a mouse. The operator needs to specify motions at a stationary state on a CRT display. Secondly the interpolation of the sequential data is considered to connect the data by continuous curve. Thirdly the introduction of rhythm in movements is discussed. The dancing motion of the CCA should harmonize and synchronize with music. The synchronization will be realized to make the velocity of a component zero with the rhythm of music. Finally some important functions of the software are summarized. Especially, it is necessary to examine whether or not the physical constraints are satisfied when the data are applied to the CCA. Final evaluation of the dancing motion will be conducted by the use of the CCA.

Fig. 1 Computer controlled automaton (CCA)

Fig. 2 Mechanism of the CCA

(a) Block diagram of the system

(b) Teaching by manual control

Fig. 3 Real-time teaching

2. Summary of the real-time teaching method and remarks

The block diagram of the real-time teaching is shown in Fig. 3(a). A human operator watches the CCA and manipulates the joystick controller at real-time so as to move the part of the CCA with music [see Fig. 3(b)]. The procedure of the teaching is as follows [3]:

- (1) A human operator listens to music carefully, and imagines the dancing motions.
- (2) In his mind the human operator breaks down the total dancing motions of the CCA into the motion of individual part.
- (3) The operator manipulates the joystick at real-time to move each part sequentially. For example, the waist is moved first, then the right arm, and so on. The corresponding position data are stored into a computer.
- (4) The dancing motion of the CCA is evaluated as a whole with the music, and modification is done repeatedly if necessary.

This method seems simple; however, it requires a considerable amount of time to achieve satisfactory dancing motions. Difficulty lies in the step (1) and step (2). An untrained person cannot imagine a good dancing motion, and it is difficult to break down the total motions into the motion of individual part. However, the most difficult work is the real-time teaching in the step (3). A human has inherent time delay to respond to a stimulus. Even if he moves the joystick quickly after listening to music, the movement of CCA is slightly delayed. Thus the movement of CCA is not synchronized with the music. The adjustment of the time axis for the trajectory of dancing motions is a time-consuming task.

A new method is proposed to overcome these difficulties.

3. Planning of dancing motions using sequential motion images

3.1 Generation of sequential motion images

To avoid the difficulty of the real-time teaching, we introduce the offline teaching of dancing motions. The direct use of the CCA for various trajectory data may cause mechanical problems. Thus we developed the skeleton model of the CCA and the offline teaching is conducted by the use of graphical image of the skeleton model. The procedure of offline teaching is as follows:

- (1) A human operator imagines the dancing motions. This is the same as in the real-time teaching.
- (2) The human operator determines the time interval of teaching based on the rhythm of the music.
- (3) The operator manipulates the mouse to move all parts of the skeleton model, and complete one graphical image at a specific time. Next, he slightly modifies the graphical image as shown in Fig. 4. In this way, the series of sequential images of the skeleton model is determined.
- (4) The data of continuous trajectory are generated by interpolating the data of sequential images. The interpolating program is explained later. Also the synchronization of the motion with music is discussed.
- (5) The total dancing motions are evaluated by the use of the skeleton model, and the modification of the data is repeated until a satisfactory result is obtained.
- (6) The final check is done by the use of the CCA with the music.

Fig. 4 Sequential image of the skeleton model

3.2 Interpolation of the data

The series of sequential data are given in the step (3) of Section 3.1. The interpolation is to connect the sequential data by continuous curve. For example, consider the interpolation of one axis shown in Fig. 5. The two data sets are Θ_i and Θ_{i+1} ; the angles are defined with some convenient reference. The simplest way of interpolation is a straight line. As is shown in Fig. 6 (a), if we connect the two points by a straight line, the angular velocity becomes a constant. In this case, the pattern of velocity is step-wise as shown in Fig. 6 (b); the angular velocity becomes discontinuous at the time when the sequential data is given. In order to avoid the discontinuity of the velocity, we introduce two straight lines for interpolation. As is shown in Fig. 7, consider new point $\dot{\Theta}_i^*$ for the angular velocity. The rotational angle is the area of hatched zone; thus, we get the following equation in order to retain the change of angle.

$$\Theta_{i+1} - \Theta_i = \frac{1}{2}(\dot{\Theta}_i + \dot{\Theta}_i^*)(T_i^* - T_i) + \frac{1}{2}(\dot{\Theta}_i^* + \dot{\Theta}_{i+1})(T_{i+1} - T_i^*) \quad (1)$$

When Θ_i and Θ_{i+1} are given, the equation determines the relationship between $\dot{\Theta}_i^*$ and T_i^* . The $\dot{\Theta}_i^*$ and T_i^* are chosen so that the maximum angular velocity and the maximum torque are under some predetermined values, which are given by the hardware specifications. If these conditions are not satisfied for any choice of $\dot{\Theta}_i^*$ and T_i^* , the time interval must be increased.

The interpolation explained here gives the continuous velocity change; however, the derivative of velocity becomes discontinuous. Thus more smooth function will be necessary to avoid the discontinuity.

3.3 Introduction of rhythm in the movements

The importance of dancing motions is to synchronize and to harmonize with music. When do we feel that a dancing motion is synchronized with music? In order to consider this point, let us examine the data of dancing motions which were generated by an experienced person. These motions have been evaluated by many laymen

Fig. 5 Angles at adjacent instant

Fig. 7 Introduction of a new point

(a) Change of angle

(b) Angular velocity

Fig. 6 Interpolation by a straight line

and judged as satisfactory. Figure 8 shows the movement of the right arm; the solid line is the angular velocity and the dashed line is the angle. The rhythm of the music is indicated by the triangles. It is clear that the velocity is almost zero when the rhythm of music exists. Thus it is effective to make the velocity zero with the rhythm of music in the program of dancing motions. Note that at least one component should obey this rule; some components may move independently to the rhythm.

In order to make the velocity zero at a specified instant, we can use the method of interpolation mentioned in Section 3.2. For example, if we want to introduce the rhythm in the interval shown in Fig. 9 (a), it is realized by choosing appropriate instant shown in Fig. 9 (b). Once again, the hatched area is equivalent to the rotational angle, and we have to choose the time and the angular velocity considering this condition.

Fig. 8 Movement of the right hand

(a) Choice of time interval

(b) Introduction of zero velocity

Fig. 9 Introduction of rhythm

Fig. 10 The flow of the whole process

4. Software for the teaching process

The teaching method using sequential motions and its procedure were explained briefly in Section 3.1. The flow of the whole process is shown in Fig. 10. The process is divided into two parts. One is the generation of sequential motion data by a human operator. The other is the generation of continuous trajectory data by interpolation. The functions of the main sub-programs are as follows.

(1) Acquisition of angle data: Based on the input generated by a human operator, the angle of a joint is calculated and changed to new angle data. The change of the angle is proportional to the movement of the mouse. Therefore, the gain of the mouse is important for a human operator to modify the angle subtly.

(2) Calculation of the skeleton model: The position of each point of the skeleton model is calculated in three dimensions by the use of the joint angle data obtained in (1).

(3) Generation of a graphical image: The projection of the three dimensional skeleton model to the two dimensional plane is conducted. A graphical image is then generated and shown on the CRT.

(4) Generation of a continuous trajectory: The interpolation of sequential data is conducted as described in Section 3.2. Also, the rhythm of the movement is introduced as shown in Section 3.3.

(5) Check of data: In order to use these data for CCA, the physical constraints should be satisfied. Usually the maximum velocity, maximum acceleration, and maximum angle are specified for each joint in advance. If the data does not satisfy the constraints, some modification is necessary. Assume that the maximum angle of the joint j is specified as M_{CCA}^j . If the corresponding maximum angle M_T^j of teaching data is larger than M_{CCA}^j , then all teaching data θ_T^j are changed to

$$\theta_{CCA}^j = \theta_T^j \cdot \frac{M_{CCA}^j}{M_T^j} \quad (2)$$

where θ_{CCA}^j are the data of the joint j for CCA.

5. Concluding Remarks

The teaching method using sequential motions is proposed for the computer controlled automata and necessary software is developed. The sequential dancing images are generated by a human using a mouse. It should be noted that this teaching method is conducted offline. The continuous data of the dancing motions are constructed from the sequential dancing images by interpolation. The rhythm of music is realized in dancing motions by making the velocity close to zero.

The proposed teaching method will reduce the time necessary for developing the program of dancing motions. In order to save even more time, the use of database will be effective. The database memorizes many patterns of dancing motions; we will choose appropriate dancing motions and combine them to make up a series of motions with music. The design and development of such a database will be a future work. Also, the automatic combination of dancing motions with music will be an interesting problem.

This kind of procedure will have a close relationship to the production of animated cartoons. Note that there is limited degree of freedom in CCA. This is advantage for developing a program. However, the generation of an impressive dancing motion is difficult under this limited degree of freedom [7].

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