Robot Choreography: Moving in a New Direction
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ARTIST'S NOTE

Robot Choreography: Moving in a New Direction

Margo K. Apostolos

ABSTRACT

The use of robots in dance—to perform dancelike motions and interact with human dancers—is discussed. Programming techniques are mentioned; also discussed are musical and movement factors, perceptual and synchronization features, and the problematic aspects of notation and safety.

Computers and robots are increasing in number and becoming common instruments in our environment. Advanced technology is changing our daily living patterns, and the world of computers and robots represents a new dimension in cultural expansion. Robot choreography has been developed to explore an aesthetic dimension of robotic movement. Industrial robots can be programmed to move in a dancelike fashion through the development of robot choreography as an integration of art and technology.

The *Encyclopedia of Philosophy* discusses aesthetics as

> the branch of philosophy that is concerned with the analysis of concepts and the solution of problems that arise when one contemplates aesthetic objects. Aesthetic objects, in turn, comprise all the objects of aesthetic experience; thus, it is only after aesthetic experience has been sufficiently characterized that one is able to delimit the class of aesthetic objects [1].

The issue of the existence, identification and definition of the aesthetic has been a philosophical concern for many years. Even to outline the issues in the debate over aesthetics is beyond the scope of this study; however, an aesthetic dimension of robotic movement is explored.

The Robot Institute of America (Palo Alto, California) defines a robot as "a reprogrammable, multifunctional manipulator designed to move material parts, tools, or specialized devices through variable programmed motions or for the performance of a variety of tasks." The microcomputer, as the programming instrument, has become an integral part of the robot.

Industrial robots are designed as manipulator arms whose actions resemble the actions of the human shoulder, elbow and wrist; in place of the head they have interchangeable grippers. An industrial robotic arm is designed to replace the function of the arm, however, and not the anatomy of the limb [2]. In a factory, the robot must act in a particular work space and perform specific utilitarian tasks (Fig. 1).

The design and manipulation of a robot involve a combination of mechanical engineering and electronics, but an aesthetic aspect need not be overlooked. Just as in dance the human body moves through space efficiently and artistically, just as a dancer performs in seemingly effortless movement, so may a robot. The graceful movement of the human form can provide a standard for the study of an aesthetic dimension of robotic movement.

Art and Technology

New materials and techniques have made change in artistic forms possible. The impact of a collaboration between art and technology is pronounced in this era of advanced technology, and the development of computer-controlled tools for the use of artists, musicians and dancers reflects the influence of technology. Perhaps our society is on the brink of an artistic revolution in the Kuhnian sense [3]; art may be in the process of taking a paradigm leap into the world of technology.

Creativity is employed by both artists and scientists. They both create through abstraction and description, although the individual process may vary between artists and scientists. The scientific approach is characterized by logical structure and the artistic approach is characterized by sensuous form. Skill and imagination are characteristics possessed by both the scientist and the artist. These characteristics are combined in the design of technologically advanced products.

Robots are machines designed to assist humans in an efficient and economical fashion. Commonly, robots have aided humans in performing dangerous and boring tasks, although the movement of the robot itself may be viewed as artistic. Robotic movement in this sense is not an abstraction from reality but rather an assistant to everyday action. However, the artistic exploration of robotics has evolved as an abstraction from reality: the film *Ballet Robotique,* for instance, depicts robots in a factory setting as they perform their work but it concentrates on the aesthetic aspect of working robots [4]. Robot choreography poses a different approach: the development of deliberately choreographed movement in a nonwork environment and unrelated to utilitarian tasks.

The Early Stages

Initially, I was skeptical concerning the idea of choreographing movement for a robot. I began with the question, "Can a robot dance?" The aesthetician Suzanne Langer speaks of dance as "a perceptible form that expresses the nature of human feeling—the rhythms and connections, rises and breaks, the complexity and richness of what is sometimes called man's 'inner life', the stream of direct experience, life as it feels to the living" [5]. Dance is an expression of

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feeling. If Langer's view of dance is accepted, then a robot cannot really be said to dance; so I prefer to say that a machine can be programmed—choreographed—in a dancelike fashion.

Although a robot is a mechanical instrument, its movement does not have to be mechanical in an artistic sense. A philosophical question arises: under what conditions is a robot to be considered an aesthetic object? A look at distinguishing criteria may establish an aesthetic distinction. Because specific criteria have not been established to determine the aesthetics of robotic movement, I have proceeded by differentiating a practical, utilitarian approach and a nonpractical, choreographic approach in programming patterns of robotic movement.

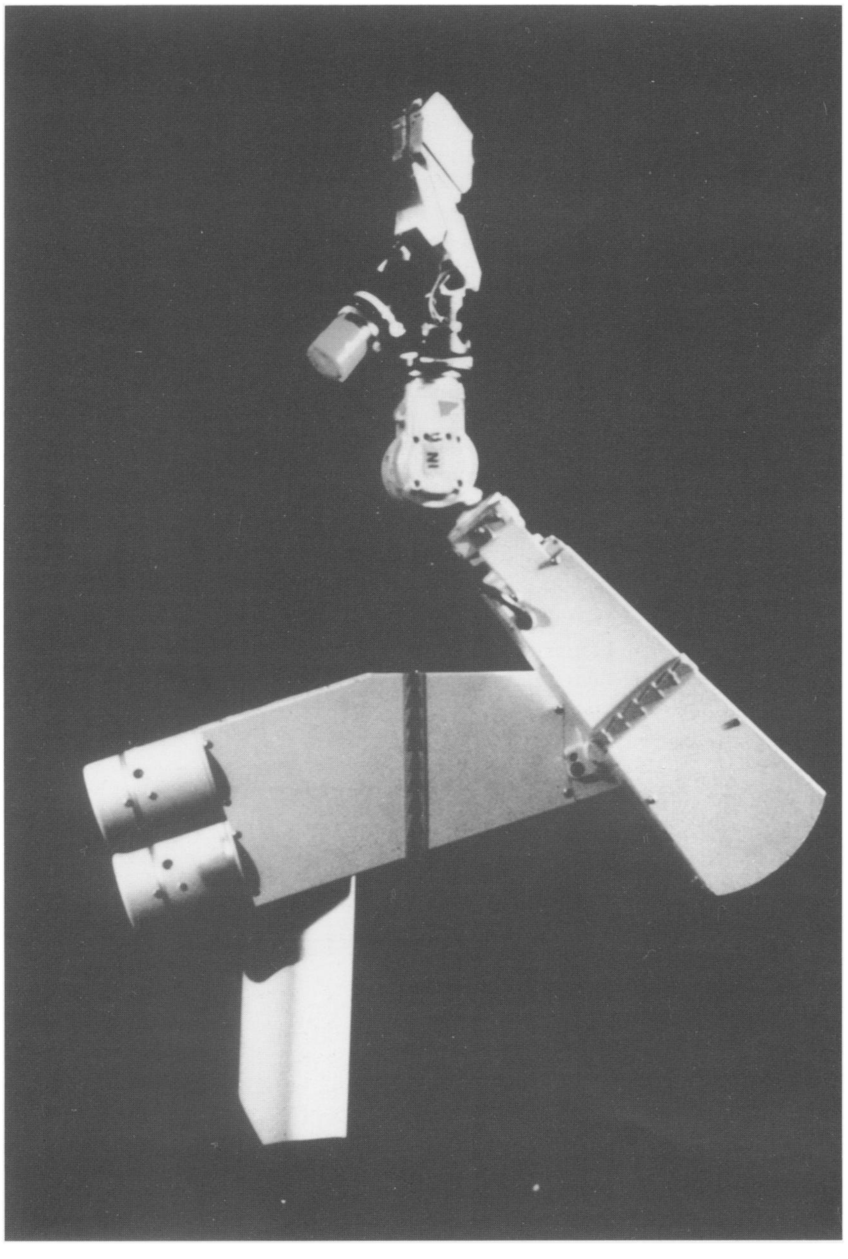
The common use of a robotic arm is to perform utilitarian tasks such as fetching objects, pick-and-place maneuvers and assembly work under the guidance of specific computer programs. The work of the robot often embodies staccato movement sequences that are incorporated for the sake of efficiency rather than for aesthetic appeal. Robotic movement that is designed to be functionally efficient is not always aesthetically pleasing.

In an attempt to make a robot move aesthetically, I have synchronized choreographed sequences with musical phrases. The mechanical features of the staccato action of the robot are contrasted with what I have defined as aesthetic maneuvers. These feature a sustained effort in the actions, smoother transitions from point to point, curved lines replacing many of the straight and sharp angular motions, and a varied sequence in the timing of movement phrases to break up the constant speed of the practical patterns of movement.

I attempt to integrate music, the forms of sculpture and the movements of dance. Choreography, the art of making dances, uses dance as a series of rhythmic motions in time and space to express ideas through movement. The process of choreographing for a robotic arm combines a logical approach with a sensuous approach in a blend of artistic and scientific creativity.

The art of dance is often bound to the notion of direct human involvement as a form of creative and expressive communication. The idea of 'dehumanized' dance is not entirely new; the works of American choreographer Alwin Nikolais were based on this concept. The Nikolais dancers moved in a mechanical style, virtually stripped of their human identity through technical effects. The dancers were manipulated through space and time by the controls of this master choreographer [6].

Fig. 1. Photo of industrial robot, the Unimation. This PUMA robot is used commonly in work environments to perform assembly tasks. The machine has six degrees of freedom.



THE CHOREOGRAPHIC PROCESS

The exploration of an aesthetic dimension in robot choreography involved (1) softening harsh lines of movement, (2) using curved lines to break up an angular effect, (3) varying the timing of movement phrases to avoid constant speed, (4) smoothing transitions between points in space, (5) defining intermediate points between movements and (6) replacing staccato actions with sustained patterns. As the choreographer and programmer, I achieved the qualitative effects of dancelike movement through intricate computer programming that focused on these elements, in which movement was synchronized with musical accompaniment.

USE OF MUSIC

Music provides a guide for movement patterns and adds another dimension to the visual aspect of choreography. An accompanist may work in synchronization with movement; dance is also performed occasionally without music or with a nonmusical accompaniment. Some choreographers prefer that the definition of the dance movement precede the music; but music sometimes inspires and structures the birth of a choreographic form. Robot choreography has used a variety of accompaniments: prerecorded piano music, improvisational cello accompaniment, computer-generated electronic music and even music generated by the robot itself. My collaboration with various musicians has been crucial in the development of this interdisciplinary work.

TYPES OF MOVEMENT

Originally, I began the development of movement phrases with a choreographic sketch for a human arm. Certain adjustments were necessary to accommodate the structure of the robot. A ballet second position *port de bras*—with arms extended sideward in the horizontal plane and parallel to the floor— was a desired form; however, the soft inward curve at the elbow joint was impossible to achieve with a robotic arm because of its fixed mounting on the work table. The elbow joint of the robot could not curve inward in a horizontal plane; the structural mounting permitted a bend only in a vertical plane.

The *port de bras* for a robot, then, was defined by focal points that corresponded to ballet positions. The movements from second position (a direct sideward horizontal position), fifth position (a direct upward vertical position) and first position (a low vertical forward and downward position) were defined to suit the robot's structure. The mechanical effect characteristic of robotic action was reduced by introducing intermediate points between the main movement points. For example, an intermediate point that brought the wrist to the shoulder was used. Thus a smoother and more sustained effort contrasted with the previously harsh transitions from point to point.

The time intervals of the movement sequences that joined two or more points in space produced varying effects; longer time intervals resulted in a sustained action, while faster sequences were used to contrast and synchronize movements. A special feature was created with various end effectors (interchangeable grippers or wrist joints) that provide a range of movement often greater than the human range. The high-speed rotation of the end effector is a pattern often used in my choreography.

RHYTHMIC SYNCHRONIZATION

Programming the robot to move precisely on certain beats of the music is a salient feature of my work. In the past, my process of synchronization has required a stopwatch; the design of a MIDI (Musical Instrument Digital Interface) interface between music and robot and between dancers and robot will reduce the time spent in synchronization. A human dancer is trained to listen for the accents and cues of the musical phrasing; hence, human dancers are skilled in responding with an individualized musical perception. The robot possesses a different advantage: once the program of movements is ordered and timed, the robot dancer performs movement patterns with remarkable precision and does them exactly the same way each time.

MOVEMENT NOTATION

Currently, work in the area of computerized movement notation is being explored [7]. Norman Badler and Stephen Smoliar have been programming computers with the highly regarded Labanotation system since the 1970s [8]. Thomas Calvert of Simon Fraser University (Vancouver, British Columbia) has been working with stick figures as models used to represent the Laban system. Calvert has also developed the graphic displays depicted by the 'sausage woman' and the 'bubble man', which provide graphic outlines of figures [9]. Joseph Menosky has defined a paramount problem in the complete development of dance notation: "The underlying problem for any language of dance is how to capture aesthetic factors" [10]. The notation only records dance movement and cannot display the aesthetic pleasure of participation or observation of dance performance. The computer process will aid movement notation by simplification and sophistication through a concise system of storage and retrieval of dance movement information. The computer and the artist will remain apart concerning the sensuousness of the aesthetic dimension. That is, the act of artistic creation remains once removed through the computer translation.

Any attempt to design a movement notation system must take limiting factors into account. In the case of robot choreography, exact replication and precision of programmed movement will be guaranteed advantages because the aesthetic dimension demonstrated in the execution of movement sequences involves the definition, recording and performance of movements at specific time intervals. An aesthetic interpretation is addressed through observation and evaluation of the performance by the artist and the audience.

The need for a universal movement notation system to assist in programming robot movement is crucial in the future development of robot choreography. Currently, 'dance steps' for robots have been created within available programming languages; for example, the Unimation PUMA robots are operated through VAL and VALII, and the Spine U.S. robots are programmed with system-specific languages. These simple programming languages make possible the recording of points in space and the development of intricate programs. Much of the programming can be done through a teach pendant that controls the movement of the robotic manipulator. The movement notation system that I have created is user-specific and not easily adapted to the needs of another programmer. A natural language interface would be desirable in the programming of robot choreography in order to create a universally translatable notation system.

A program for robot choreography consists of various routines and subroutines. Individual points are named and recorded as movement points in space. These points are linked together into movement phrases that constitute the subroutines and routines. An example of a program for the Unimation PUMA 560 written in VALII is given in Table 1 [11].

A program is defined by choosing a designated name, i.e. 'box'. Step 1 is a speed command, i.e. '40'. Step 2 moves the robot to a particular point in space recorded as '#bx1a'. Step 3 indicates a one-second pause. Step 4 is another speed command. Steps 5–10 move the robot to various designated points in space. Step 11 ends the program. Most of my programming and choreography is done from the joint mode, that is, by manipulating each joint of the robot independently. This particular program can be linked to other programs in a master routine.

Individual points are recorded with

Table 1. A program for robot choreography.

```
PROGRAM box
1    SPEED 40 ALWAYS
2    MOVE #bx1a
3    DELAY 1
4    SPEED 50
5    MOVE #bx1a
6    MOVE #bx2
7    MOVE #bx3
8    MOVE #bx4
9    MOVE #bx5
10   MOVE #bx6
11   RETURN
```

reference to joint angles. Most of the robots that I have worked with are manipulated with six degrees of freedom. The degrees of freedom refer to specific joints on the limb, each joint representing one degree of freedom: shoulder rotation joint (1), shoulder flexion and extension joint (2), elbow flexion and extension joint (3), wrist rotation joint (4), end effector flexion and extension joint (5), and end effector rotation joint (6). These joint positions are stored within the system and recorded with the point names indicated in the programs. The joint angles are in the system's memory and are relative to the position of robot calibration.

Safety Factors

A robot is a machine capable of causing injury to humans within its work envelope, which is defined as the space within the reach of the machine. This space generally is off limits to humans while the machine is operated. In robotics laboratories and factories precautions are taken to avoid the potentially hazardous work space. When the robot is moved from the laboratory into another setting, extra safety measures must be taken. In dance, all humans should remain outside of the robot's reach. Figure 2 thus depicts a dangerous moment in the relationship between a dancer and a robot on stage.

The integration of robot and human dancers in a theatrical setting can challenge the efforts directed toward creating a safe performing environment. Human dancers seem less aware of the potential dangers of robots than workers in industry. Dancers are not familiar with robots or the possibility of errors within the system; keeping dancers out of the robots' work envelope is a difficult but essential task (Fig. 3).

Conclusion

The 'dance' for a robotic arm is both an expression of the choreographer's imagination and an audience's perception of the work. Robot choreography demonstrates an artistic-scientific combination that blends various talents and tools into a unitary piece: the sculpture of movement in space, the musicality of rhythmic movement responses in time, and the expression of the symbolic gesture of dance. Choreography for a robot may be compared to kinetic sculpture, which provides a visual representation of rhythmic motion in time and space. A dancing robot is possible as the creative expression of both the artist and the scientist and is perceived by the audience through the transmission of the work of art.

The development of the features of robot choreography have involved the selection of certain aesthetic criteria. The fluidity and timing of the compositions have been a significant element. The constant speed of the mechanical actions is reduced by varying the speed between movement points in space. Although straight-line actions may be used for contrast and accent in a dramatic moment, I have favored curved lines to soften the mechanical aspect of movement lines.

The aesthetic implications of human movement do not apply directly to the actions of the robot arm. Choreography for a human arm actually works a

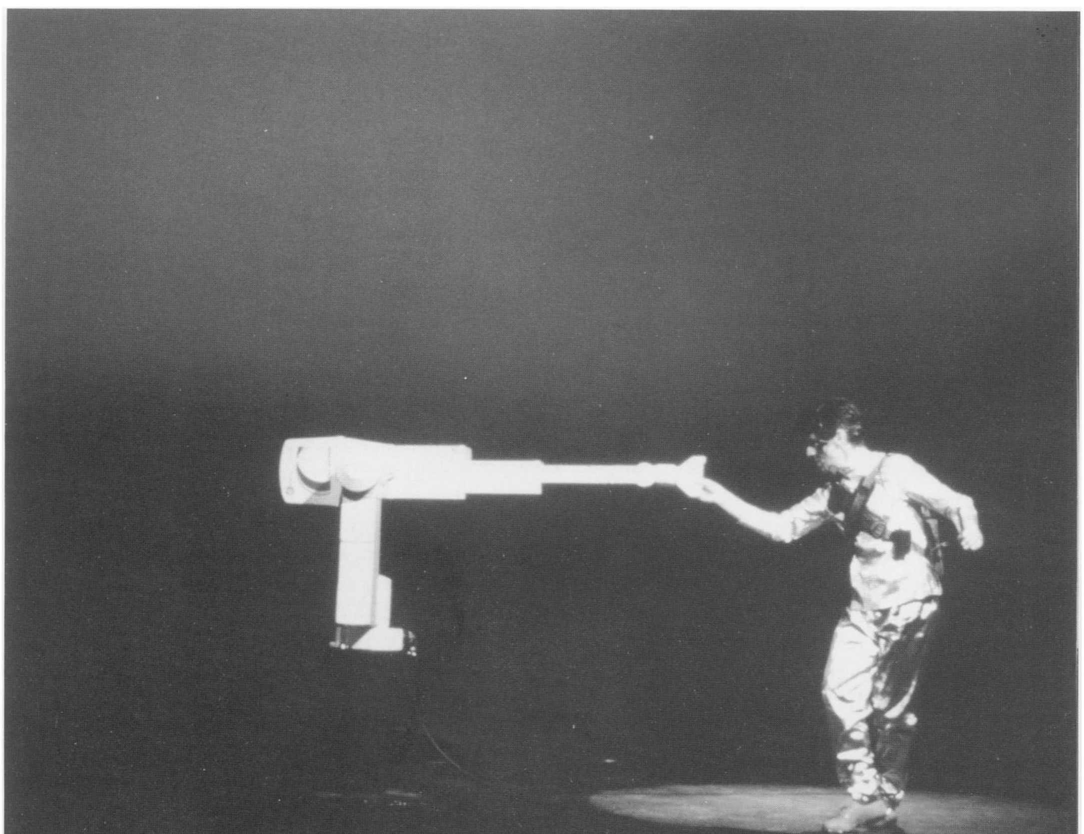


Fig. 2. Tap dancer and robot. Professional dancer Alfred Desio performs with the U.S. MAKER 110 robot to illustrate a close human/machine interaction. The photo captures Desio in a dramatic moment within the robot work envelope.

Fig. 3. Dancers and robots in performance. Members of the University of Southern California Dance Theatre in performance with the U.S. MAKER 110 robot and the Unimation PUMA 560 in a segment from the production of the *Mars Suite*. The student dancers perform around the robots in a safety zone.

body part in relation to the whole body. The impetus of the torso and head is often an indirect action or reaction to the isolated limb. The human arm may appear to work alone, but the movement results with relation to the whole body.

The range of movement of a robot may be greater than its human counterpart in certain cases, such as wrist action, and less than the human in other cases, such as shoulder action. The design of robot motion cannot be compared directly to that of human motion but must be interpreted and evaluated as a separate entity.

A robot is unable to provide an unsolicited response to musical sequences, while a dancer often assists a choreographer by demonstrating an individual musical perception and assisting the movement-music synchronization. However, an advantage of the computer/robot method of choreography is the exact replication of preprogrammed movement phrases, a task not easily assured in human dance performance.

Art and technology have progressed both philosophically and practically: as technology creates new, advanced products, artists find ways to use them. The aesthetics of robot motion is an example of a union between the worlds of art and science. Choreographic techniques can be used to enhance the application of robot technology, and the widespread use of robots may have a significant influence on artistic trends, particularly in the development of kinetic art forms.

The similarities between kinetic art and robot choreography may expand the artistic perspective of robot movement. The idea of exploring the aesthetic dimensions of robotic movement demonstrates an innovation in movement, perhaps similar to kinetic sculpture. The machine choreography used in the kinetic arts and the forms of kinetic sculpture closely resemble in part the designs of robot choreography. Both kinetic art and industrial design provide a framework for the development of the aesthetic dimension of robot movement.

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