Humanoid Motion Description Language

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Abstract

In this paper we propose a description language for specifying motions for humanoid robots and for allowing humanoid robots to acquire motor skills. Locomotion greatly increases our ability to interact with our environments, which in turn increases our mental abilities. This principle also applies to humanoid robots. However, there are great difficulties to specify humanoid motions and to represent motor skills, which in most cases require four-dimensional space representations. We propose a representation framework that includes the following attributes: motion description layers, egocentric reference system, progressive quantized refinement, and automatic constraint satisfaction. We also outline strategies for acquiring new motor skills by learning from trial and error, macro approach, and programming. Then, we outline the development of a new humanoid motion description language called Cybele.

1. Introduction

Locomotion greatly increases our ability to interact with our environments, which in turn increases our mental abilities. The principle that mental abilities can be improved by interacting with the environments is the basis for MIT Cog's project [Brooks 98]. However, Cog robot currently lacks locomotion. On the other hand, Honda Humanoid Robots [Honda] possess the state of the art locomotion system, but lack the autonomy and the learning abilities. We envision the union of these two types of robots as the basis of our investigation.

The humanoid robots of the near future will possess the abilities for locomotion, autonomy, and learning. Much research remains to be done on such autonomous humanoid robots. In this paper, we will focus on issues of developing a common framework for both specifying motions and for autonomously acquiring motor skills for such robots.

A unified framework to address both specifying motions and acquiring motor skills will facilitate the developments of autonomous humanoid robots. Neural Network, for example, may be a good medium for capturing and classifying motor skills. However, the resultant representation in terms of matrix of weights of connectivity is difficult to be interpreted and modified. Thus, in this investigation, we choose to use symbolic approach by developing a description language.

Our humanoid motion description language, like any other languages, consists of syntactic and semantic aspects. Syntactic aspect specifies rules for combining words while semantic aspect specifies structures for interpretation and such provides the meaning. We propose different set of words and rules for different level of abstraction, such as using joint angles at low level and using walk and jump at high level of abstraction. The interpretation and the meaning are based from our framework that includes egocentric reference system, progressive quantized refinement, and automatic constraint satisfaction.

Our language and our framework are unique in many ways comparing to other related research. Our reference system simplifies specification of locomotion and allows motions to be described by uniform and deterministic expressions. Our concept of Progressive Quantized Refinement allows a humanoid robot to interact with its environments using different level of granularity. Our Automatic Constraint Satisfaction system reduces the complexity of specifying humanoid motions. Moreover, our underlining model using non-deterministic finite state machines allows humanoid robots to learn new motor skills.

Research in describing humanoid motions begins with the works for describing human dances. Popular dance notation systems include Benesh [Causley 80], Labanotation [Hutchinson 87], and EW [EW]. Benesh is the simplest one and is designed particularly for dance description. Labanotation is more comprehensive for describing human motion in general. EW can be applied on linkage systems other than human body. Computers are now used to aid the interpretation and visualization of these notations [Singh 84] [Adamson 87] [Calvert 93] [Schiphorst 92]. Researchers used

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Labanotation as a basis to represent human motion, proposed to extract key motion primitives, and proposed architectures for digital representation of human movements [Badler 79]. Another approach uses natural language; such as "Improv" system used natural language to script human behavior interacting in virtual environments [Perlin 96]. Motion sequences can be generated by system that employs human biomechanical logic [Badler 94].

2. Specifying Humanoid Motions

The proposed language and framework for specifying humanoid motions includes the following attributes: motion description layers, egocentric reference system, progressive quantized refinement, and automatic constraint satisfaction, each of which is described as follows.

2.1 Motion Description Layers

Table 1 outlines the concept of motion description layers. Each description layer is a level of abstraction. Joint Angle layer describes a motion in terms of changes in the joint angles, such as knee joint rotate to 30 degree or elbow joint rotate to 45 degree. This layer provides detail and precise information that can readily be used to control various actuators of a robot. Path layer describes a motion in terms of a connected line that is specified by points. A simple path can be specified using two points, such as Hand (v1) that moves hand from current position to point v1. More points provide more detail specification of the path; for example, Foot (v1, v2) denoted that foot moves from current position through v1 to v2.

Motion primitive layer describes a motion in terms of a given set of essential motions that can be combined to form more complex motions. The set of essential motions must first be identified. It must be complete so that we can describe all possible motions of a humanoid robot. We must also provide a set of rules for specifying how one motion primitive can be combined with another. In effect, we are creating a formal language and insuring that the language is both complete and consistent. This is an axiomatic approach to describe humanoid motions.

Table 1. Motion Description Layers

Description Layer	Example
Motion Sequence	Walk, Run, Jump, Turn
Motion Primitive	Raise, Lower, Forward, Backward
Path	Hand (v1), Foot (v1, v2)
Joint Angle	Knee Joint 30, Elbow Joint 45

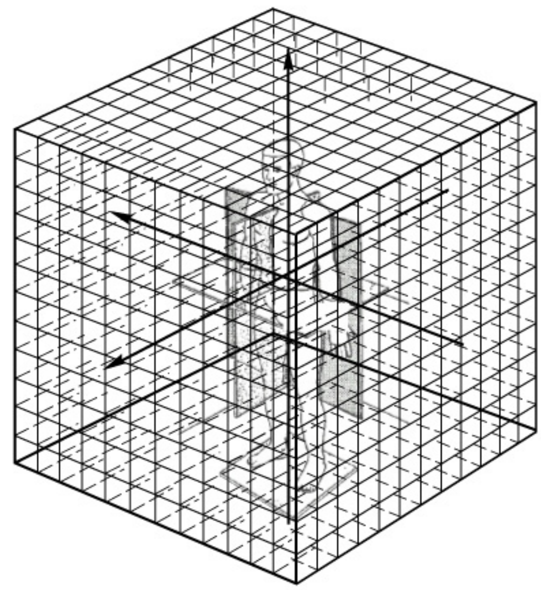

Figure 1. Egocentric Space Reference System

Motion sequence layer describes a sequence of motions in terms of motion blocks such as walk, run, jump, and turn. Using this high-level description, we can describe a complex task with ease without having to specify the angle of each joint. However, this high-level description is not as precise as low-level description and thus leaves must room for interpretation that is addressed in this investigation by using Progress Quantized Refinement discuss in Section 2.3.

2.2 Egocentric Reference System

We proposed an egocentric reference system for specifying space-time in discrete finite four-dimensional hyperspace. Each point in our reference system is represented by a quintuple (x, y, z, t). Each of the variables, x, y, z, and t, is an integer ranging from –128 to +127. The origin of the reference system locates at (0, 0, 0, 0). In short, each point in our reference system can be stored using four bytes or 32 bits.

Our reference system is egocentric in that the origin of space is located at the center of the torso of a humanoid robot, as denoted in Figure 1. The origin of time is located at the beginning of a state transition.

In our system, a motion is defined by a sequence of state transitions. Each state transition begins at time 0 and must be completed in 127 time units or less. Negative time units represent the time units used during the last state transition. Each state transition begins with the origin of space located at the center of the torso. In short, a state transition begins at (0, 0, 0, 0). All changes during a state transition are specified within the egocentric reference system.

Translation between the egocentric reference system and its world reference system is done at the end of each state transition. For example, beginning at a standing position as shown in Figure 1, the robot moved three units forward in positive y-axis direction and completed at a standing position, and the whole transition takes 9 units of time. Now, the center of the torso is located at (0, 3, 0, 9). Assuming at the beginning of the transition R(0, 0, 0, 0) in the robot's egocentric reference system is located at W(3, 2, 4, 2) in its world reference system. Also assume that y-axes of both systems are parallel and have the same direction, and each unit in the egocentric reference system represents 2 units in the world reference system. To reset R(0, 3, 0, 9) back to R(0, 0, 0, 0), we makes R(0, 0, 0, 0) now to corresponding to W(3, 2+3*2, 4, 2+9*2).

2.3 Progressive Quantized Refinement

We proposed a concept called Progressive Quantized Refinement for a humanoid robot to interact with its environments using different level of granularity. Figure 2 illustrates the concept; on the left picture a 9x9 unit squares is used to display a room while on the right picture the same sized 9x9 unit squares is used to display part of a table. For a robot to put an object on the table, the robot can first use the left picture to move toward the table. Then, it can use the right picture to put the object on the table.

At different states a robot can change its unit scale factor as needed. For example, a unit length in the robot's egocentric space reference system can be scaled to 1 cm, 1 inch, or 1 meter in its world reference system. A unit time can be scaled, for example, to 1 second, 1 minute, or 5 minutes.

2.4 Automatic Constraint Satisfaction

We proposed to use Automatic Constraint Satisfaction to reduce the complexity of specifying humanoid motions. There are many implicit requirements for locomotion, such as maintaining balance and structural integrity. Automatic constraint satisfaction system will provide additional changes to meet the implicit requirements.

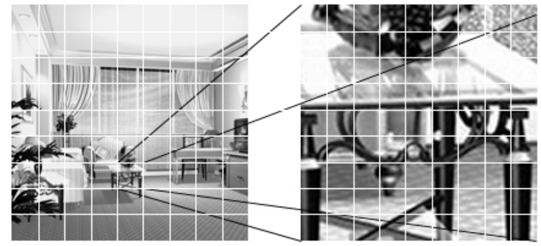

Figure 2. Concept of Progressive Quantized Refinement

A system for providing automatic constraint satisfaction for locomotion is very complex and much research is being done on areas such as motion planning and constraint satisfaction. For example, we can simply specify that the robot must move its right hand from current position (3, 6, 2, 0) to new position (3, 50, 2, 6). The simpler the specification, in most cases, requires the more complex constraint satisfaction. In our example, the hand must reach the new position using 6 units of time, so that speeds for various actuators must be adjusted to meet this requirement. If the hand cannot reach the new position by simply raising it and reaching out, then the robot must move the whole body toward the new position.

3. Acquiring New Motor Skills

The ability for acquiring new motor skills is essential for mental developments. The trivial approach is to simply program a humanoid robot for new required motor skills, which can easily be done by an experienced programmer using our proposed language and framework. Thus, in the following, we will focus on strategies for acquiring motor skills through learning from trial and error and learning by macro approach.

3.1 Learning Motor Skills

Learning motor skills has not yet been a central focus of Machine Learning researchers. Thus, much research remains to be done on automatic acquiring new motor skills. We briefly outline strategies for creating such a system, which in part is based on the first author's work on automata for learning sequential tasks [Choi 98].

3.1.1 Learning from Trial and Error

One way for acquiring new motor skills is by trial and error. This approach requires first identifying an objective and then selecting actions or motions to achieve the objective. In particularly, using our proposed framework, identifying an objective can be described as identifying a goal state, while selecting actions or motions can be described as selecting a sequence of transitions from the current state to the goal state.

Using our proposed framework, the underlining model is a non-deterministic finite state machine. From one state, there may be several transitions to follow to other states. Choosing one transitions or the other is why we call this a trial and error approach and is why it is non-deterministic. To achieve the objective is to find a sequence of transitions from the current state to the goal state. As soon as a sequence of transitions is found, it can be stored for future use.

3.1.2 Learning by Macro Approach

Macro approach can be used in a supervised learning environment. After a humanoid robot is repeatedly instructed to perform certain task, the robot can store the sequence of motions to associate with a name of the task. After which, the robot can be commanded to perform the sequence by simply specifying the name of the task. This is a simple record and play back approach.

A more sophisticated approach is provided by the first author [Choi 98], in which a robot can build a non-deterministic finite state machine based on the repeatedly instructions to perform certain task. The resulting non-deterministic finite state machine can then be used for other purposes such as for learning from trial and error as discussed above.

4. Developing Cybele

We are developing a humanoid motion description language, called Cybele, based on our proposed framework. Our development process in turn enhances the strength of our framework. More detail description of our new language will be provided in our future papers.

5. Conclusion and Future Research

We described our proposed description language and framework for specifying motions for humanoid robots and for allowing humanoid robots to learn motor skills through interacting with the environments. The proposed language and framework are unique and encompassing many areas of research interesting to researchers in epigenetic robots. This paper can also serve as an outline of strategies for future research programs in humanoid motion description and motor skill acquisition. Much work remains to be done in this exciting new area of research.

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