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Research article

Generation of rhythmic hand movements in humanoid robots by a neural imitation learning architecture

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ABSTRACT

This paper presents a two layer system for imitation learning in humanoid robots. The first layer of this system records complicated and rhythmic movement of the trainer using a motion capture device. It solves an inverse kinematic problem with the help of an adaptive Neuro-Fuzzy Inference system. Then it can achieve angles records of any joints involved in the desired motion. The trajectory is given as input to the systems second layer. The layer deals with extracting optimal parameters of the trajectories obtained from the first layer using a network of oscillator neurons and Particle Swarm Optimization algorithm. This system is capable to obtain any complex motion and rhythmic trajectory via first layer and learns rhythmic trajectories in the second layer then converge towards all these movements. Moreover, this two layer system is able to provide various features of a learner model, for instance resistance against perturbations, modulation of trajectories amplitude and frequency. The simulation results of the learning system is performed in the robot simulator WEBOTS linked with MATLAB software. Practical implementation on an NAO robot demonstrate that the robot has learned desired motion with high accuracy. These results show that proposed system in this paper produces high convergence rate and low test error.

Introduction

One of the key capabilities of the organisms that play an essential role in their growth and survival is moving. Ability to perform a variety of complex movements in vertebrates is considered as a part of their intelligence that implicitly embedded in their organs and nervous system. Engineering with inspiration from a variety of live animals has produced robots and several cars that require performing similar movements with biological samples.

Movement generation is creating some sets of control trajectories which are forwarded to a robot to perform a complex maneuver or movement. Generated trajectories should be based on robot high level aims for doing a job. They should be produced in a dynamic and intelligent way to consider environment conditions and sensor data. Generating robotic movements is a challenging task that is hard, costly and require a lot of processing and analysis. Hence the need for machine learning methods with complex behaviors that can be taught in a favorable way to automation is quite tangible. In machine learning, the goal is to design a system that can learn and improve their performance through experience. Machine learning methods are based on the data type of the intelligent agent. They are divided into three general categories: supervised learning, unsupervised learning and semi-supervised learning (Anderson, Michalski, Carbonell, & Mitchell, 1986).

Imitation learning is a subset of supervised learning for training complex tasks to a robot. The method is also known as learning by demonstration, learning from demonstration and programming by demonstration. Similar to the human infants, an artificial system can also learn through demonstration. The system proposed in this paper consists of layers for teaching rhythmic movement to the NAO humanoid robot (Fig. 1). The first layer of this system, uses motion capture device to records movements such as karate kicks and dumbbells kicks. It records from human teacher and using required analyses attains trajectory of motion angles of each joint. These trajectories are taught with using the second layer. This job would be done to learn the required parameters for a complete motion such as dumbbell pressing, karate and exercise. The second layer and its training algorithm is explained in the paper. This two layer learning system is able to provide various features of a learner model, for instance resistance against perturbations, modulation of trajectories amplitude and frequency.

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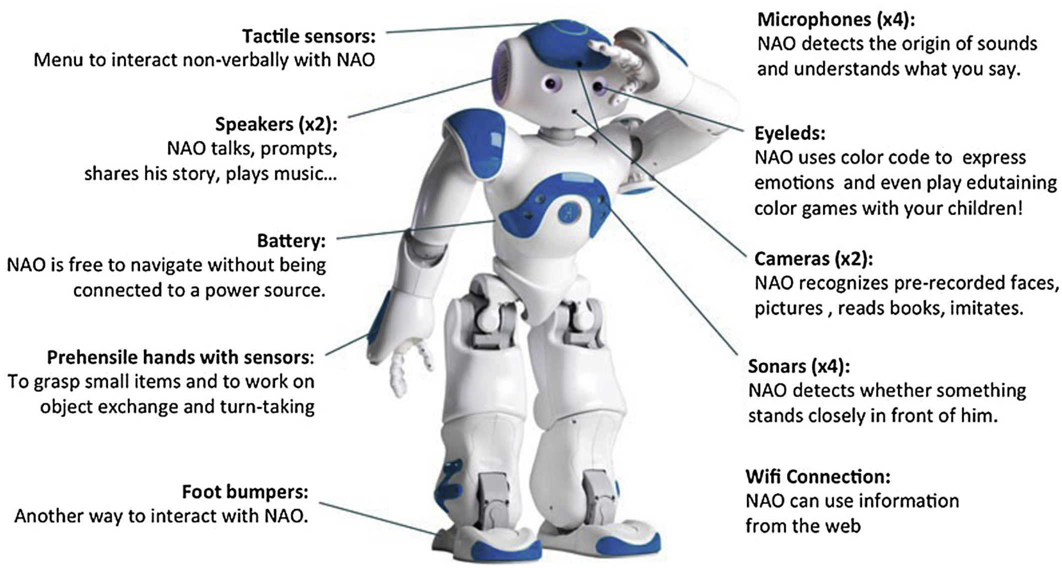

Fig. 1. NAO humanoid Robot.

Related work

Argall, Callinon and Kubota used time-dependent approaches to learn and model motion trajectories. This approach is an accurate and efficient modeling techniques to describe the trajectory. It uses an explicit time priority over moving parts to accurately reproduce the work. However, these methods require complex calculations to modify the policy for various behaviors and also do not resist against perturbations. Argall, Browning, and Veloso (2008), Calinon and Billard (2009), and Kubota and Wakisaka (2009). Ijspeert, Nakanishi, and Schaal (2002a, 2002b) proposed an approach in order to eliminate the challenges of time-dependency. Time independent approaches is provided for learning discrete movements based on dynamic systems with using nonlinear differential equations. To learn rhythmic movements using nonlinear dynamic systems, the central component of their model is some standard nonlinear oscillators. This method can learn some movements from human teacher and reproduce them from the changes or modified behavior. The main objection to this method is that it requires the recorded signal frequency to be obtained by signal processing techniques such as Fourier analysis. To eliminate the dependency to the signal processing techniques, Righetti, Buchli, and Ijspeert (2005), has used the equations of coupled adaptive oscillators for learning desired trajectories. Adaptive mechanism here are based on a Hebbian based method in artificial neural networks which is called Hebbian learning. The adaptive oscillator is able to adapt dynamically its frequency with any periodic or semi-periodic signal. Hackenberger (2007) is using a set of amplitude-phase oscillators. This model of oscillators is actually a description of Hopf adaptive oscillators in polar coordination. Since the rate of convergence in the expressed methods is not fast enough for many of the patterns, error does not reach to zero. That is why that, after a specified period of time the error (which is the input of each oscillator) should be divided by the square root of time. It can be said that the major problem we face to use Hebbian method is the lowness of the convergence rate and destabilization of the parameters such as amplitude, phase and frequency of the trajectory. This latter problem causes a higher error between the desired trajectory and the learned one. To solve this problem in this paper another technique is proposed. This technique increases the convergence rate and decreases the error between the desired trajectory and the learned one.

System modeling

In this section the two layer model of imitation learning for training rhythmic and complex movements to a humanoid robot is described.

Systems first layer modeling

The purpose of this layer is to obtain the trajectory of each joint of the robot to learn rhythmic movements such as karate kicks, dumbbell kicks and other exercises. For this purpose, the movement information from a human teacher is captured by a motion capture system. This system consists of seven cameras that record the movements of the markers installed in appropriate positions on the human teacher arms. Cameras record the marker's positions in a discrete way and in each time step. By defining and assigning an inertia orthogonal three dimensional Cartesian coordinate device (with three orthogonal axes x, y, z), the coordinates of these positions could be saved and then analyzed by QTM software. Based on the coordinates of the markers, The system could convert the coordinates to their comparable coordinates in joint space. In this paper for each arm according to Table 1 is considered.

Based on the theory of inverse kinematic using just the position and orientation coordinates of each wrist, all angles of joints could be obtained. Solving inverse kinematic equations that is referred in the robots mechanics and dynamic methods, needs some complex computations. In this paper the inverse kinematic problem is solved by an ANFIS (adaptive Neural Fuzzy System). First, based on the allowed range of angle variations for each DOF, 30 uniform data is generated and then we combine these data to reach 304 sets of angles (each set includes four angles). Each of these sets is given to the model created in MATLAB. The compared coordinates of the robot wrist are calculated by forward kinematics. For each set of angles x, y, z coordinates the comparable position of robot wrist is determined. For each of these seven data types (four data of angle type and three coordinate component) 9 triangular membership functions are defined in order to convert the data to some fuzzy sets. Also Takagi-Sugeno method is used to create fuzzy rules. This data is used to train the ANFIS neural network. Thus, using fuzzy learning, the neural network learns to output a set of angles according to the robot wrist position that takes as input, that it is the purpose of the inverse kinematic problem. Using the