

Dance Choreography Design of Humanoid Robots using Interactive Evolutionary Computation

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Abstract

This article deals with a usage of artificial intelligent techniques in humanoid robotics. The focus is on social robotics and how to improve the interaction between human and robot. We used the interactive evolution for robotic dance system. In this work the definition, principles and basic features of Interactive Evolutionary Computation are described. This technique optimizes systems based on subjective human evaluation. The algorithm is applied to a system of design of robotic dance, in which the evolutionary algorithm helps user to create choreography of the robotic dance. The system was implemented in language Python and simulation environment Webots. The experiments with several human subjects show that the interactive genetic algorithm approach to robotic dance choreography design aid system is promising.

Keywords

Human-Robot Interaction, Genetic Algorithm, Intelligent Systems, Robotic Dance

I. INTRODUCTION

Jorge Luis Borges in his *The Library of Babel* writes about a library which consists of indeterminate and infinite number of books. Most of them contain nonsense and rational relation is almost miraculous exception, but somewhere there are books that contain all the knowledge of the universe.

A traveler in such a Library wanting to find something rational has a very difficult task, as the most of the books are just a cluster of incomprehensible letters. How we could help this traveler to find a "masterpiece" in the endless space of options? We need a tool that would fly in this space effectively and thanks to it we would find something inspiring. One of such a tool could be an evolutionary algorithm.

The discipline of artificial intelligence (AI) builds computational systems inspired by various aspects of life. An evolutionary algorithm is an optimization algorithm which uses some mechanisms inspired by biological evolution coming out from Darwinian Theory. More and more AI researchers are trying to make robots dance. We used a form of evolutionary algorithm called Interactive Evolution to design a system of Robotic Dance for humanoid robots. User interactively co-operates with the System designing his own robotic dance choreography. The interaction between humanoid robots and people is the key factor of their success, because they must exist in a human environment.

This work is divided as follows.

Section 2 describes current research in the field of humanoid robotics focusing on methods of artificial intelligence used in humanoid systems. The application domain of robotic dance is analyzed. This section also presents theory of evolutionary algorithms describing the principles of interactive evolution and its main research questions.

Section 3 gives the proposal of system which uses interactive genetic algorithm as a tool for creating robotic dance choreography. Further, we implement the multi-robot system in experiments with a group of Nao robots and in simulation using Webots, which is a 3-D simulator of robots.

Section 4 reports on the results of the experiments and section 5 concludes the work with a short summary and discussion of the results.

II. ARTIFICIAL INTELLIGENCE IN HUMANOID ROBOTICS

A. Research in humanoid robotics

The focus of robotic research continues to shift from industrial environments, in which robots must perform a repetitive task in a very controlled environment, to mobile service robots operating

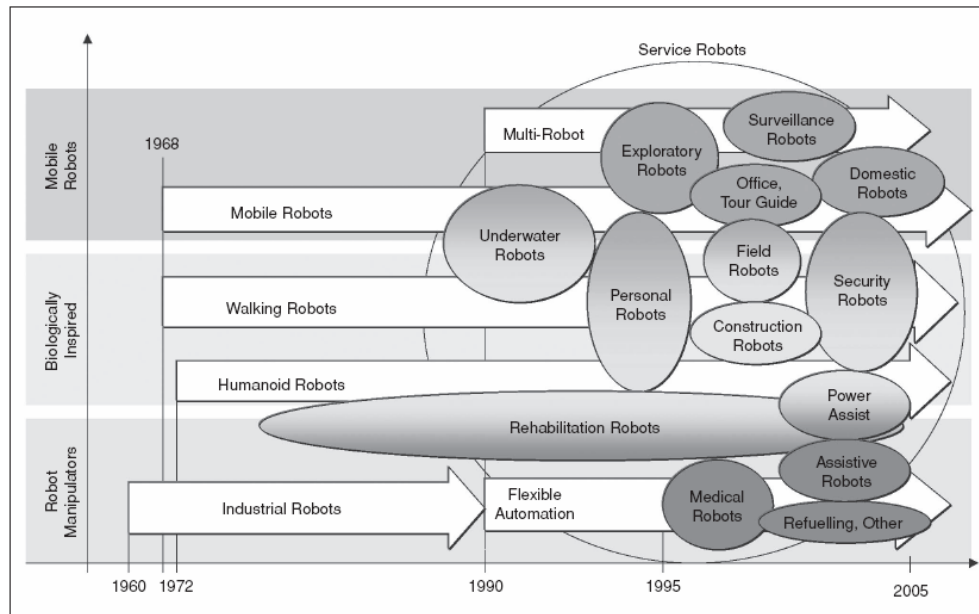


Fig. 1. Time evolution of the robotics research towards service robots (GARCIA, E. - JIMENEZ, M., A., 2009 [3]). The authors conclude that robotics research is moving from industrial to field and service applications. A group of defenders of the development of human-like personal robots advocate the importance of aiming at such challenging tasks because of the technology that can be developed, which would prove very important from the commercial point of view in other industrial activities.

in a wide variety of environments, often in human-habited ones. There are robots in museums, domestic robots that clean our houses, robots that present news, play music or even are our pets. These new applications for robots make arise a lot of problems which must be solved in order to increase their autonomy. These problems are, but are not limited to, navigation, localization, behavior generation and human-machine interaction.

According to Brooks [2], the implicit dream of Artificial Intelligence has been to build human level intelligence. Building a humanoid is the challenge par excellence for AI and robotic workers. Recent generations of humanoid robots (HR) increasingly resemble human in shape and capacities.

Humanoid robots are robots that are at least loosely based on the appearance of the human body. Talking about humanoids in community of AI, by humanoid we mean not only a robot that has the physical appearance of a human, but also has a fairly advanced artificial intelligence, allowing it to reasonably approximate human behavior and interactions.

The main goal of HR is to insert humanoid robots into the human environment - new trends in research consider the robots ability to interact with people safely and in natural way. The current leading topics in HR are so-called service and social robotics - where the target is getting robots closer to people and their social needs. There are many attempts to create robots capable of expressing emotions or communicating in a natural language.

Research topics in human-robot interaction according to [3] include the following:

- 1) Friendly human-robot interfaces,
- 2) Safe human-robot interaction,
- 3) Emotion expression and perception,
- 4) Social learning.

The wide spectrum of applications of interactive robotics proves the importance of the way we will work and cooperate with robots - for example they will assist in health care, rehabilitation, and therapy, serve as tour guides, office assistants and household staff.

Social robots will engage us, entertain us, and enlighten us. Thus, although it is important to continue enhancing autonomous capabilities, we must not neglect improving the human-robot relationship.

B. Dance in humanoid robotics

Dance is a largely social activity - whether for aesthetic pleasure, entertainment, communication or ceremony - and is likely linked to our innate socially.

Numerous works on robotic dance systems are presented in [1]. Researchers at the University of Tokyo have developed the learning-from-observation training method, which enables a robot to acquire knowledge of what to do and how to do it from observing human demonstrations. At

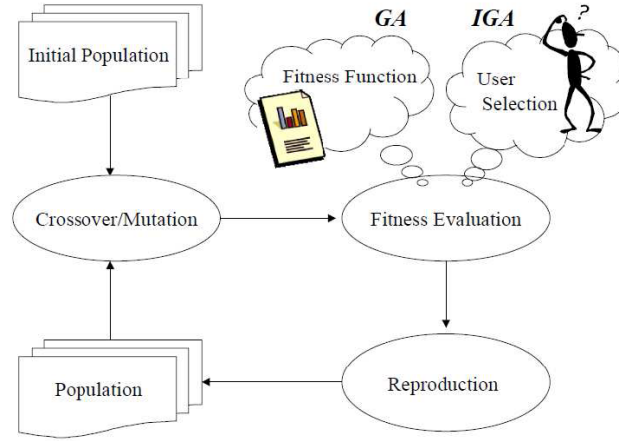


Fig. 2. The process of Genetic Algorithm and Interactive Genetic Algorithm where the fitness function is replaced by the subjective user evaluation (TAKAGI, H., 2009 [5]). The interactive EC is the optimization technique based on the subjective scale. Humans evaluate the distance between the goal and a system output in psychological space. On the other hand, EC searches in a parameter space. The interactive EC is a system that humans and EC cooperatively optimize a target system based on the mapping relationship between the two spaces.

the Kyoto University apply a method called intermodality mapping to generate robot motion from various sounds and also to generate sounds from motions using the back-propagation through-time algorithm. Other approach from Tokyo University is using Chaos to trade synchronization and autonomy in a dancing robot. Dancing Robot Partner built at the Tohoku University is well-known in the domain of robotics. Their robot acts as a female partner and realizes ballroom dances in coordination with a male human dancer by estimating his intention.

Although some of the mentioned systems are examples where interaction between human and robot is the key factor of their success, they are exceptions in the world of robotic dance. The majority of dance systems of robots are only pre-programmed motions and after a while user find them boring. The proposed system in this work interacts with human and the motion is evolving in accordance with his evaluation of the seen dance section.

C. Use of artificial intelligent methods in humanoid systems

Artificial intelligence (AI) tries to make programs or computers do things that, when done by people, are described as having indicated intelligence. The goal of AI has been characterized as both the construction of useful intelligent systems and the understanding of human intelligence. Since AI's earliest days there have been thoughts of building truly intelligent autonomous robots. In academic research circles, *work in robotics has influenced work in AI and vice versa* [2].

Neural networks, fuzzy logic and evolutionary computation have influenced the development of intelligent algorithms. Thanks to their strong cognitive skills and learning abilities, tolerance of uncertainties and other characteristics are applied in many applications of advanced control in humanoid robotics. Large importances in the development of efficient algorithms have hybrid techniques as the neural fuzzy, fuzzy neural or neural genetic and fuzzy genetic systems. These combine the properties of mentioned techniques. Each of them has its advantages and limitations. Hybrid technology - its integration and synthesis (sometimes called symbiotic intelligence) is necessary for the effective application of humanoid robotics because they make possible to avoid many of the limitations of the individual techniques.

In our work we used genetic algorithm to build a dance choreography of a humanoid robots.

D. Basic features of evolutionary computation

Evolutionary computation is a biologically inspired general computational concept and includes Genetic Algorithms (GA), Genetic Programming and Evolutionary Strategies.

The EC is a population-based searching algorithm and outputs multiple candidates, each called an individual, as system outputs. Genetic algorithm is a probabilistic search algorithm based on the mechanics of natural selection and natural genetics. The space of all feasible solutions (it means objects among those the desired solution is) is called search space (also state space). Each point in the search space represents one feasible solution. Each feasible solution can be "marked" by its value or fitness for the problem. The chromosome should in some way contain information about solution which it represents. The most used way of encoding is a binary string. Crossover selects genes from parent chromosomes and creates a new offspring. After a crossover is performed,



Fig. 3. Our user-interface for simulation of robotic dances in Webots and connected with evolutionary algorithm in programming language Python. User interactively co-operates with the system evaluating the showed dancing performance of each robot and gives them marks according to his own opinion and preferences.

mutation takes place. This is to prevent falling all solutions in population into a local optimum of solved problem. Mutation changes randomly the new offspring.

General GA process is as follows:

- 1) Initialize the population of chromosomes.
- 2) Calculate the fitness for each individual in the population using fitness function.
- 3) Reproduce individuals to form a new population according to each individual's fitness.
- 4) Perform crossover and mutation on the population.
- 5) Go to step 2) until some condition is satisfied.

GA provides a very efficient search method working on population, and has been applied to many problems of optimization and classification.

E. Interactive evolution

There are two types of target systems for system optimization: systems whose optimization performances are numerically - or at least quantitatively - defined as evaluation functions and systems whose optimization indexes are difficult to specify. IEC is an optimization method that adopts EC among system optimization based on subjective human evaluation. It is simply an EC technique whose fitness function is replaced by a human user. We can say that the IEC is a technology that embeds human preference, intuition, emotion, psychological aspects, or a more general term, KANSEI, in the target system.

There are many applications when the fitness function cannot be explicitly defined. Interactive evolutionary algorithm uses human's response as fitness value. This enables algorithm to be applied to artistic domains, and we propose a dance choreography design aid system for humanoid robots using it.

The article published by Takagi [5] gives a survey of all achievable knowledge about the Interactive Evolutionary Computation (IEC).

III. DESIGN AND IMPLEMENTATION OF ROBOTIC DANCE EVOLVING SYSTEM

A. Motivation

The goal of dance choreography design is to create some 'nice dance performance'. We can apply GA for dance choreography design by initializing the population of individuals encoded from dance characteristics, setting and evolving the fitness as how nice the design of this dance is. However, there is no general standard of 'beauty of dance', and it is almost impossible to organize fitness function. IGA might be a solution for this. IGA can reflect personal preference because it perceives fitness directly from user instead of computing using some function. Figure 3 shows how user evaluates the seen dances.

Part	Joint name	Motion	Range (degrees)
Head	HeadYaw	Head joint twist (Z)	-120 / 120
	HeadPitch	Head joint front & back (Y)	-39 / 30
Left arm	LShoulderPitch	Left shoulder joint front & back (Y)	-120 / 120
	LShoulderRoll	Left shoulder joint right & left (Z)	0 / 95
	LElbowRoll	Left shoulder joint twist (X)	-90 / 0
	LElbowYaw	Left elbow joint (Z)	-120 / 120
	LWristYaw	Left wrist joint twist (X)	-105 / 105
	LHand	Left hand	open/close
Left leg	LHipYawPitch	Left hip joint twist (Z45°)	-44 / 68
	LHipPitch	Left hip joint front and back (Y)	-104.5 / 28.5
	LHipRoll	Left hip joint right & left (X)	-25 / 45
	LKneePitch	Left knee joint (Y)	-5 / 125
	LAnklePitch	Left ankle joint front & back (Y)	-70.5 / 54
	LAnkleRoll	Left ankle joint right & left (X)	-45 / 25
Right Leg	RHipYawPitch	Right hip joint twist (Z45°)	-68 / 44
	RHipPitch	Right hip joint front and back (Y)	-104.5 / 28.5
	RHipRoll	Right hip joint right & left (X)	-45 / 25
	RKneePitch	Right knee joint (Y)	-5 / 125
	RAnklePitch	Right ankle joint front & back (Y)	-70.5 / 54
	RAnkleRoll	Right ankle right & left (X)	-25 / 45
Right arm	RShoulderPitch	Right shoulder joint front & back (Y)	-120 / 120
	RShoulderRoll	Right shoulder joint right & left (Z)	-95 / 0
	RElbowRoll	Right shoulder joint twist (X)	0 / 90
	RElbowYaw	Right elbow joint (Z)	-120 / 120
	RWristYaw	Right wrist joint twist (X)	-105 / 105
	RHand	Right hand	open/close

Fig. 4. Names of joints of robot and possible motions - range in degrees (from the documentation available also on internet - <http://www.aldebaran-robotics.com>)

B. Humanoid Robot Nao and his simulators

Humanoid robot Nao comes with 25 degrees of freedom for great mobility as showed in Table 1. The inertial sensor and closed loop control provide great stability while moving and enables positioning within space. Its state-of-the-art onboard actuators give Nao extreme precision in its movements [4].

It supports multiple programming environments and programming languages like URBI Script, C++, Python, .Net Available on Linux. It can be programmed and controlled using Linux, Windows or Mac OS. The most used simulators for Nao are Microsoft Robotics Studio, Gostai Urbi Studio, Pyro, Choregraphe and Webots. The simulator gives a relatively faithful representation of the Nao robots. Choregraphe is a cross-platform application that allows you to edit Nao's movements and behaviors.

It comes with a closed source software framework called NaoQi which is the only way to access the robots actuators and sensory. It also provides basic components for image acquisition, walking, and actuator pattern execution.

Degrees of freedom of the robot Nao are placed as follows:

- Head: 2
- Arms: 5 in each arm
- Pelvis: 1
- Leg: 5 in each leg
- Hands: 2 in each hand (0 in RoboCup edition)

Robot functionality is encapsulated in software modules. In this work we intensively use of them called *ALMotion*. This module provides a set of methods to move the robot motors. There are methods which set a joint angle, methods which let us to set robot chains (head, foots, and arms) to a desired cartesian position, and methods which provides a high level functionality, such as walking movement.

The position in angles of the degrees of freedom - servos or motors of the robot will represent the phenotype of the genetic algorithm, as seen in figure 5.

C. Proposed interactive genetic algorithm

We used an interactive genetic algorithm, which enables user to create his own dance choreography of robot Nao. The genetic algorithm was implemented in Python - an interpreted,

The outputs of experiments are dances so it is very difficult to represent them by images. In figure 6 we can see one example of the postures in dance in the third generation of evolution.

The convergence of the algorithm to the similar dance motions, depending on evaluation, is observed in 6-10 generations. Many interactive EC tasks do not require a large number of generations to achieve satisfactory results [5]. Due to the good initial convergence of EC, unlike gradient methods, the human fatigue problem may be fewer than gradient searches. Task characteristics of subjective searches and numerical combinational optimizations are quite different, and the former does not have the exact optimum point. This is why it is sufficient for the human evaluated task to reach to an optimum 'area' rather than one point, which searches out a satisfactory solution with fewer searching generations.

We have not included the motion of legs of the robot yet - we worked with head servos, arms and torso of Nao.

After the experiment, the subjects answered a questionnaire about their subjective evaluations of the system. Our subjects - observers estimated positively the easy use of the proposed system so we consider the GUI user-friendly. They also coincided that system is a helpful tool to create new robotic dance choreographies.

V. CONCLUSION

This work presented a multi-robot system capable of evolution of dance choreography using interactive genetic algorithm. It was implemented in simulation with seven robots.

Results showed that the interactive genetic algorithm approach to robotic dance choreography design aid system is promising. The model was a good first approximation of the system that in near future would engage people in face-to-face interaction.

In future work we plan to extend the phenotype with new features like LEDs and music recognition. The robot Nao has a human-like appearance and various sensors for interacting with humans so we want to extend the interaction between observers and robots in creating new dances. We performed an experiment to evaluate the developed system and analyzed if it is a good aid for unexperienced observers to create their own robotic dance.

We believe that the interactive evolutionary computation will make interactive robots more personal in interacting with humans. The global idea is that every person can adapt in our case the dance choreography, in accordance to his own expectations and preferences. Also, our approach of IEC can be applicable to various purposes in humanoid robotics, such as designing the behaviors of robots and their communication and interaction with humans.

Our global dream is for Nao to acquire its own mental model of people. Currently, he does not reason about the emotional state of others. It means that we want to extract the information about the own preferences of human during his evaluation of the behaviour of the robot in the interactive evolutionary algorithm and make this process autonomous. The ability to recognize, understand, and reason about another's emotional state is an important ability for having a theory of mind about other people, which is considered by many to be a requisite of adult-level social intelligence (Brooks, Breazeal, 1999 [2]).

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