Co-evolutionary Approach to Design of Robotic Gait

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Abstract. Manual design of motion patterns for legged robots is difficult task often with suboptimal results. To automate this process variety of approaches have been tried including various evolutionary algorithms. In this work we present an algorithm capable of generating viable motion patterns for multi-legged robots. This algorithm consists of two evolutionary algorithms working in co-evolution. The GP is evolving motion of a single leg while the GA deploys the motion to all legs of the robot. Proof-of-concept experiments show that the co-evolutionary approach delivers significantly better results than those evolved for the same robot with simple genetic programming algorithm alone.

1 Introduction

Walking robots have advantage over wheeled ones when navigating complex and uneven environments. However, to fully use abilities of a particular legged robot it is necessary to optimize its gait specifically for its mechanical structure, dimensions and parameters.

This is a highly challenging task seeking for a coordinated control of many joints, given multiple (often contradictory) optimization objectives such as the maximal or some specific speed of locomotion, low-energy operational mode, stability of the robot, etc. The solution sought must also comply with multiple constraints. Typically, the state transitions have to be continuous in order to attain smooth gait patterns. Other constraints can be determined by limited resources and mechanical parameters that determine inherent capability limits of the robot [3]. Moreover, the optimization objectives as well as the constraints are non-linear, in general.

Obviously, manual generation of gaits is very difficult, if feasible at all, due to the aspects mentioned above. Utilization of standard numerical optimization methods is limited since the objective functions are not defined analytically (each candidate gait is evaluated by a real experiment or through a simulation), hence no information about continuity or differentiability is available. Single-state heuristic methods that work in point-to-point manner are ineffective as well since they are very prone to get stuck in some sub-optimal solution when searching huge space with many local optima.

A.I. Esparcia-Alcázar et al. (Eds.): EvoApplications 2013, LNCS 7835, pp. 550–559, 2013.

On the contrary, evolutionary algorithms (EAs) are population-based search and optimization techniques that have been used for solving hard optimization problems of the black-box type. Unlike the single-state heuristics, the search direction is adjusted using the information accumulated over all candidate solutions of the population in each generation step of the EA run. Thus, the EAs are more resistant to getting trapped in a local optimum. They are also resistant to noise in the evaluation function, which is very important for this particular optimization domain.

There have been many studies devoted to the evolutionary design of systems for automated gait generation and gait optimization of biped, quadruped, and hexapod robots [3]. Several types of gait representation has been used by evolutionary-based gait generators. Genetic Programming and Grammatical Evolution evolve directly the functions defining the joint angle trajectories [6]. One example of this approach is in the work of Ivan Tanev who used it to create controllers for artificial snakes [7]. Another approach to this problem is evolution of Central Pattern Generators (CPG) [2]. Those are type of neural network with the ability to generate rhythmic patterns.

The research presented in this paper is based on modular robotic creatures that are composed of a number of simple cubic-shaped robotic blocks. The robotic blocks are endowed with a movable arm and several slots that they use to connect to each other (realizing joint-like connections) to form complex structures. Joint angles are controlled by functions of a single input, time, that return desired joint positions at discrete time steps. Thus, the generation of the gait consists in finding a set of functions (a single function for each joint) that make the whole robotic creature to move in a desired way. We assume multi-legged robots that exhibit features of symmetry and module repetition. Particularly, a quadruped robot was investigated in this work.

In this work we consider just simulations of the robot and its gaits that are carried out using a simulation platform Sim, based on ODE physics simulator[1], which has been developed within the SYMBRION and REPLICATOR[2] projects [4], focused on an application of evolutionary and swarm techniques in robotics.

The primary goal of our research was to design an effective and efficient evolutionary-based system for automated generating of robot gaits and experimentally evaluate its performance. To attain the goal, a co-evolutionary system was proposed that resolves the whole task by decomposing it into:

- The evolution of a single-leg motion pattern, i.e. evolution of functions controlling movement of all joints of a single leg. This part is realized by genetic programming.
- The evolution of the coordination strategy that optimally deploys the evolved single-leg motion pattern to all legs of the robotic creature. This part is realized by genetic algorithm as the coordination strategy is represented by a linear vector of control parameters that are to be tuned.

[1] www.ode.org

[2] http://www.symbrion.eu/tiki-index.php