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Procedia Computer Science 7 (2011) 320–322

Procedia Computer Science

The European Future Technologies Conference and Exhibition 2011

Locomotion Gait Optimization For Modular Robots; Coevolving Morphology and Control

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Abstract

This study aims at providing a control-learning framework capable of generating optimal locomotion patterns for the modular robots. The key ideas are firstly to provide a generic control structure that can be well-adapted for the different morphologies and secondly to exploit and coevolve both morphology and control aspects. A generic framework combining robot morphology, control and environment and on the top of them optimization and evolutionary algorithms are presented. The details of the components and some of the preliminary results are discussed.

Keywords: Robotics locomotion; Modular robotics; CPG-based control; Evolutionary Algorithms

1. Introduction

Traditional approaches for designing optimal locomotion controllers for specific desired behaviors usually separate the problem of robot design from the control design. Recent studies have shown the benefits one can obtain through co-evolution of robot control and morphology. This approach first was used and presented by Sims [1]. Pfeifer et al. [2] emphasized the advantages that can be achieved by exploiting morphology in parallel with control aspects. Following these ideas in order to explore the different possible solutions for optimal locomotion performance, we propose a framework combining morphology, control and environment of the robots. For the robot morphology we use modular robots to facilitate building and testing several different robot morphologies. Locomotion control is performed by using CPG-based control since it provides an approach suitable for distributed implementation, robust to environmental perturbations and easy and flexible to modulate and optimize. The approach we use is based on the concept of central pattern generators (CPGs) [3], as found in the spinal cord of vertebrate animals. CPGs implemented as coupled oscillators can generate rhythmic coordinated movement patterns. On the top of these components, optimization and evolutionary algorithms are used to evolve morphological and control parameters of the robots. In the next section, these components and some of the preliminary results are introduced and discussed.

2. Control and Learning Architecture

The architecture we propose integrate three main basic components, robot morphology, control and environment are in interaction with each other i.e. the CPG network topology of the robot matches the robot morphology (Fig. 1b) and the optimizations on both of them is influenced by the environment. We use different methods to evolve morphological and control parameters including stochastic optimization methods (such as particle swarm optimization) and evolutionary algorithms for the objective of morphology and control co-evolution.

 doi:10.1016/j.procs.2011.09.084

2.1. Robot Morphology

Robots are constructed using Roombots modular robot. Roombots are modular robots with three DOFs per module capable of both oscillatory and rotational joint movements and generating rich and diverse locomotion patterns (Fig. 1a). However the framework is generic and the building blocks can be replaced by any other

2.2. Control Architecture

We extend our previous CPG formulation [4] by using nonlinear output filters. This framework offers different but synchronized joint movement patterns including Rotational and Oscillatory movements as follows.

$$\dot{\phi}_i = 2\pi \cdot \omega_i + \sum_j w_{ij} \cdot r_j \cdot \sin\left(\phi_j - \phi_i - \psi_{ij}\right) + f_{\theta i}(\vec{s}); \quad \dot{r}_i = a_i(R_i - r_i) + f_{r_i}(\vec{s}) \tag{1}$$

$$\left.\left.\begin{array}{ll} \theta_i = r_i \cdot \sin(\phi_i) + X_i & (Oscillation) \\ \theta_i = \phi_i & (Rotation) \\ \theta_i = X_i & (Locked) \end{array}\right\}\right\} \text{servo inputs} \tag{2}$$

where θ_i is the servo input which can be derived with different functions corresponding to the desired joint movement. Variables r_i and ϕ_i encode amplitude and phase of the oscillation. The parameters w_{ij} and ψ_{ij} are respectively the coupling weight and phase shift of the coupling between oscillators i and j. a_i is a positive constant and the parameters R_i, X_i, and ψ_{ij} are open parameters.

3. Results and Discussions

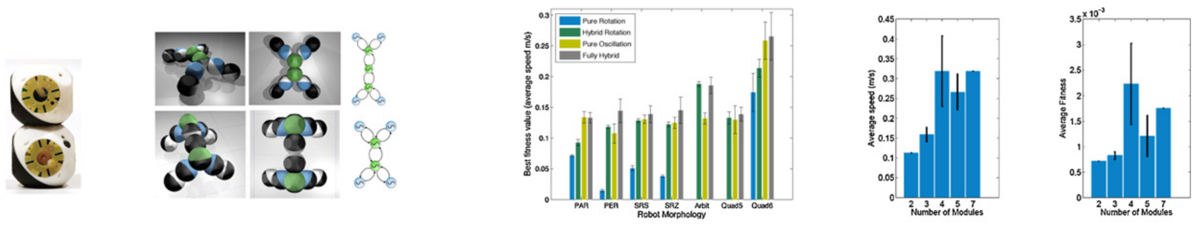
We use two different experimental setups to evaluate the performance of the generic controller structure as well as the co-evolution approach for the morphology and control.

3.1. Evaluation of Generic Control Framework

We test four different control structures for several different morphologies including four different meta-modules, one asymmetric robot with three modules (Arbit) and two quadruped shapes (Quad5 and Quad6, (Fig. 1b)). Figure 1c shows that the hybrid generic framework outperforms the other approaches (for more details please refer to [5]).

3.2. Evaluation of Co-evolution Framework

In this set of experiments, the set of open parameters includes both CPG parameters (amplitude, offset and phase lags) and morphological parameters (number of modules, inter-connections, connection types and number of DOFs). Several experiments are performed with different initial populations to optimize the robots for fast and efficient locomotion. The fitness value here includes speed, energy efficiency and smoothness of the gaits. Figure 1d shows that robots with four modules offers fitter and more diverse solutions. Several interesting solutions for the robot shape and also locomotion patterns are generated which would be hard to imagine or to be hand-tuned by human.



(a) (b) (c) (d)

Figure 1. (a) One Roombots module, (b) Different robot morphologies built by Roombots modules with their corresponding CPG network, (c) Results for the evaluation of generic controller structure and (d) for the co-evolution of morphology and control.

4. Conclusions

We have proposed a framework which provides a wide range of locomotion patterns and robot morphologies in order to explore wider space of solutions for fast and efficient robotic locomotion. Results show that using these approaches one can achieve better and more diverse solutions. Our research on this topic will be further pursued in order to address the problems of how to properly include environmental effects through using sensory feedback.

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