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Automatic generation of biped locomotion controllers using genetic programming

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HIGHLIGHTS

- Automatic generation of biped locomotion with minimal knowledge about the task.
- Inclusion of sensory information enables adaptation of the locomotion.
- Results demonstrate the relevance of feedback in adapting locomotion to sloped ground.
- Inclusion of sensory information generates locomotion more entrained with the robot.

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ABSTRACT

Generating biped locomotion in robotic platforms is hard. It has to deal with the complexity of the tasks which requires the synchronization of several joints, while monitoring stability. Further, it is also expected to deal with the great heterogeneity of existing platforms. The generation of adaptable locomotion further increases the complexity of the task.

In this paper, Genetic Programming (GP) is used as an automatic search method for motion primitives of a biped robot, that optimizes a given criterion. It does so by exploring and exploiting the capabilities and particularities of the platform.

In order to increase the adaptability of the achieved solutions, feedback pathways were directly included into the evolutionary process through sensory inputs.

Simulations on a physic-based Darwin OP have shown that the system is able to generate a faster gait with a given stride time with improved gait temporal characteristics. Further, the system was able to cope with tilted ground within a specific range of slope angles. The system feasibility to generate locomotion more entrained with the environment was shown.

1. Introduction

There is an increasing interest in building autonomous systems to aid humans performing tasks in a wide variety of situations. Ranging from space and deep ocean exploration, or rescue missions in hazardous environments, to in everyday tasks, such as cleaning the house or taking care of the elderly. In most of these cases, legged locomotion may provide for an advantage over wheeled or tracked robots. It offers a higher level of flexibility required in a wide variety of terrains and the ability to deal with harsher terrain features, e.g. stairs, obstacles, uneven or irregular terrain. Particularly, biped locomotion provides the flexibility to a world shaped for humans. The control and generation of biped locomotion for the ever improving biped robots is a very demanding task, addressing complex problems as the generation of the movements and coordination between many degrees of freedom, balancing, perception and planning, and disturbance rejection.

Typical solutions to the problem of biped locomotion make extensive use of the knowledge of the robot and environment. Generally a plan of the path and foot placement sequence is determined, then the required motions are computed using the robot's kinematical model, respecting determined constraints established through some stability criterion, as the popular Zero-Moment Point [1,2]. However, such approach requires a good perception of the environment which may hamper the general application to different dynamic environments.

Alternatively to these typical solutions, bio-inspired approaches have been researched and proposed with quite successful results. One of these approaches uses the concept of Central Pattern

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Generators (CPGs), exploiting the interesting characteristics of intraspinal neural networks in vertebrates [3]. These generate rhythmic activation for walking motor patterns. CPGs have been widely used to address the biped locomotion generation problem [4–8] for several commercial robotic platforms (*e.g. DARWIN-OP and NAO*). The main characteristic that motivates for the application of CPGs in the generation of robotic legged locomotion is the ability to adapt and correct the locomotion by the integration of sensory feedback pathways [9,10]. This provides the ability for the robots to deal with unexpected disturbances and more dynamic, not completely known environments. Hybrid approaches include CPGs and Center of Pressure (CoP) [11] or ZMP [12].

Previously, we have proposed a CPG based solution for biped locomotion [5]. It combines a small set of motion primitives within CPGs driven by phase oscillators, producing basic but very capable biped walking for the DARwIn-OP humanoid robot. Despite the simplicity of the solution, the expansion of the repertoire of motion primitives to broaden the locomotor behaviors has proven complex, as well as the design of feedback mechanisms for the adaptation and correction of locomotion. Some authors tackle this adaptation problem through imitation and learning from demonstration [13], optimization of parameterized trajectories [14,15], for instance, by applying Genetic Algorithms (GA) [16,17], Genetic Programming (GP) [18,17] or reinforcement learning [19–21]. Besides, in [22] techniques in evolutionary robotics were used to explore the potential of a purely reactive, linear controller to control bipedal locomotion over rough terrain. This work is specially important in the sense that is able to achieve robust bipedal walking without including oscillatory neural structures.

In this work, we take a distinct approach. Our assumption is that adaptability is a very important characteristic of any controller if the system is expected to continuously adapt its behavior to the surrounding environment. This is an essential aspect if the robot is expected to cope with uncontrolled, unpredictable and dynamic worlds. In order to achieve this, a self-tuning movement is necessary as a response to the environment's properties. Therefore, the motor action should be driven by the sensory input, through feedback pathways that couple the movement generation to the environment perception. Besides, our assumption is that movement is generated through the combination of simple, brick primitives, herein considered discrete and rhythmic implemented as sinusoidal and bell-shaped motion primitives. The number, combination and tuning of these primitives need to be determined, and will result in different motor behaviors.

One of the difficulties was to specify primitives for each joint, such that the movement resulted in a gait with a given stride length. We took inspiration from the determinants of human walking [23], but it remains the question of whether the used combination of primitives was the most adequate to generate that particular gait. Therefore, herein authors apply GP to determine the primitives which optimize a given criterion. Normally, in the literature, the most used criterion are related to displacement, energy and jerk minimization. Herein, we decided that displacement is a good criterion since in order to generate a gait with a given stride length, the different joints and environment will have to be fully synchronized.

Regardless of the type of environment, locomotion is achieved by the rhythmic contraction of muscles attached to limbs, wings, fins, etc. Typically, a gait is efficient when all the involved muscles contract and extend with the same frequency and different phases [24]. Ijspeert et al. [25] concluded in their studies of the salamander locomotion that "from a dynamical systems point of view, locomotion becomes the limit cycle behavior of the controller-body-environment system".

Prokopenko [26] has shown that maximal coordination (measured information theoretically) was achieved synchronously with fastest locomotion (a direct measure). He showed that actuators are well-coordinated in individuals with fastest locomotion.

Evolutionary Computation (EC) algorithms rely on the concept of Darwin's evolution theory to find optimized solutions for a target problem, such as Genetic Algorithms (GA) and Genetic Programming (GP). The former considers a control policy whose configuration is evolved as a string of chromosomes—configuration parameters for a target problem. The latter evolves a complete control program for the task at hand. These methods use a fitness function that evaluates the candidate solutions, or individuals, and whose value is used as quality measure for a set of evolutionary operators (selection, crossover and mutation).

Candidate solutions in GP, or individuals, can fully describe the solution to the target problem, not requiring any a-priori structure. Therefore, although the complexity of the search space is increased, it is expected to generate more adequate solutions to a particular problem.

The idea of applying Evolutionary Algorithms for generating gait controllers for bipeds is not new. However, up to our knowledge, usually these works address parametric optimization, and not so much the optimization of the structure of the gait controller. In such case, it is required a more flexible scheme than the GA binary representation.

We apply GP to automatically search the solution landscape and find solutions that rely on a set of motion primitives. We also explore the inclusion of feedback pathways, through sensory inputs, as leaves of the GP tree, as a means to enable adaptation to the environment features, particularly to adapt the locomotion to walk up and down slopes in the environment. Specifically, in this work the goal is to apply GP to the automatic exploration of: (1) the motion primitives within the CPG, and (2) the integration of sensory inputs into feedback mechanisms for the adaptability to the environment.

Different simulations with a physics based simulator involving a commercially available robotic platform enable to assess the different aims. Firstly, it is considered the role of optimization and the role of the external feedback modulation in improving the gait temporal features, such as velocity, stride length and energy. We are particularly interested in the impact of sensory inclusion in the robot behavior. A functional analysis including roll, pitch, the Center of Mass (CoM) and Center of Pressure (CoP) trajectories, force sensors and ground clearance assess robot behavior. This provides for an understanding of how feedback enhanced the locomotion skills of a biped robot.

Next, the adaptation of the system to tilted surfaces is explored. For that, a case study is shown that assesses the viability of the biped system to be able to walk adaptively on tilted ground and the capability of the controller to provide more stable gaits on upslope/downslope terrains within a specific range of slope angles. Finally, a more complex simulation, in which the robot faces terrains with positive, zero and negative slopes, is implemented to verify the feasibility of the methodology to broad the locomotion.

Note we aim to verify the role of adaptability, achieved through feedback, in movement generation in irregular terrain, considering the achieved velocity. For that we have chosen a stable and slow gait, with a given stride duration, for which both approaches (including and not the feedback inputs) are expected to generate feasible locomotion controllers. The selected stride duration was based on previous work of the authors [5] in which a hand-tuned CPG architecture was able to stably walk with that stride duration. The fact that we use a long stride duration enables to generate solutions that provide for a stable locomotion. This stability facilitates the comparison of the achieved results in terms of the functional analysis. Future work could include determining which was the best stride duration for which feedback enhanced the improvement in the velocity. However, this was out of the scope of this paper.