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Humanoid Robot Gait Optimization: Stretched Simulated Annealing and Genetic Algorithm a Comparative Study

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Abstract. There are several approaches to create the Humanoid robot gait planning. This problem presents a large number of unknown parameters that should be found to make the humanoid robot to walk. Optimization in simulation models can be used to find the gait based on several criteria such as energy minimization, acceleration, step length among the others. The presented paper addresses a comparison between two optimization methods, the Stretched Simulated Annealing and the Genetic Algorithm, that runs in an accurate and stable simulation model. Final results show the comparative study and demonstrate that optimization is a valid gait planning technique.

Keywords: Humanoid Gait. Simulated annealing. Genetic Algorithm. Optimization.
PACS: 02.60.Pn

INTRODUCTION

Humanoid robots increased its popularity due to new concepts: service and edutainment robotics. This fact boosted research and competition teams to develop new applications and tools for such robots. One of the most important topic for humanoid robots researchers is the gait planning that is the pattern of movement for the limbs during locomotion and it depends on speed, terrain, the maneuver and energetic efficiency. Moreover, gait generation and optimization still remain a challenge for such a high-order highly-coupled nonlinear dynamical system [1]. This is a complex problem with high dimensional solutions that should be optimized.

Creating gait can be approached in two ways: the online (done in real-time that requires high computational effort) and the offline gait generation methods. This offline approach, brings some advantages such as the ability to use complex algorithms to find an optimal solution.

The humanoid robot gait planning is an interesting area to apply optimization methods over a simulated robot.

In order to generate walking patterns for different locomotion kinematics, the common way of most existing approaches is to precompute reference trajectories [2]. Similarly and based on previous authors works [3] using precomputed reference trajectory, this paper presents a comparative study between the Stretched Simulated Annealing (SSA) and the Genetic Algorithm (GA) optimization methods for the humanoids robots gait.

SSA and GA methods are stochastic techniques for the global optimization, they try to find the global maximum of a given objective function in a large search space, as it happens in humanoid gait planning. In the humanoid gait planning problem, it is needed to maximize the step distance in a large search space, where the optimization problem has 100 variables.

Before the optimization on the real robot, several iterations were evaluated using a simulated model of the humanoid robot. The simulations were conducted in *SimTwo* [4], a physical robot simulator that is capable to simulate user-defined robots in three-dimensional space since it includes a physical model based on rigid body dynamics (the *ODE* - *Open Dynamics Engine* [5]). More and more accurate models have been implemented in SimTwo that increase the reality in the Improved Simulation Model [6].

The paper is organized as follows: Section 2 presents the developed Simulator (*SimTwo*) and the robot modeling with its parameters. Then, in Section 3, the optimization techniques based on Stretched Simulated Annealing and the Genetic Algorithm methods are addressed. Section 4 presents a discussion of results and finally, the last section concludes this work and gives some future work on this topic.

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SIMULATION MODEL

The simulation is increasing due to the processing capacity available in today's computers. More accurate models and body dynamics engines speed up the games and simulators allowing to study the robot's behaviour without real hardware. The physics engine is the key to making simulations useful in terms of high performance robot control [7]. The dynamic behaviour of the robot (or multiple robots) is computed by the ODE (Open Dynamics Engine [5]), which is a free library for simulating rigid body dynamics.

There are several simulators with humanoid simulation capability. SimTwo, as a developed simulator, is a generic simulator that allows the access to the low level behaviour, such as dynamical model, friction model, servomotor model and sensors model in a way that developed code can be easily transferred to the real robot. The developed simulator allows to build several robots. SimTwo was developed having in mind the full access to all control levels and the possibility of adding several sensors, actuators and its modeling. Besides, it owns a new precise and stable joint model that allows to simulate a robot with a high number of joints in a chain architecture without instability and noise (previously presented in [6]). SimTwo also allows to run simulations faster than real time: a very useful property to accelerate the research task. A snapshot of the developed simulator is presented in Figure 1.

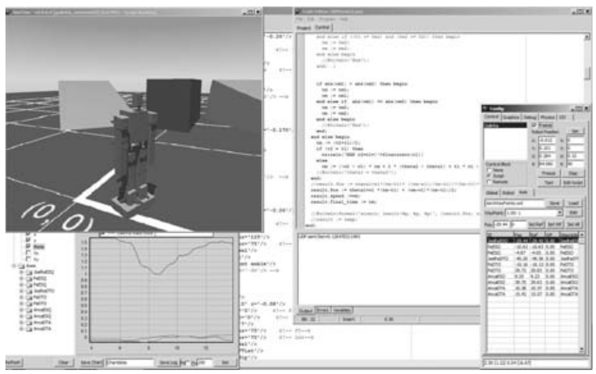

FIGURE 1. SimTwo simulator environment.

The dynamics realism in SimTwo is obtained by decomposing a robot in rigid bodies and electric motors (joints). Each body behaviour is numerically simulated using its physical characteristics such as shape, mass and moments of inertia, surface friction and elasticity. It is also possible to define standard joints such as socket, hinge and slider which can be coupled with an actuator or a sensor. Previous works validates the realism of the SimTwo simulator [8].

The gait-planning is one of the fundamental problems in humanoid mobile robots. The problem of gait planning for humanoid robots is fundamentally different from the path planning for wheeled robots due to the inherent characteristics of legged locomotion. The main challenge of gait planning is to find constraint functions and their associated gait parameters. However, finding repeatable gait when the constraint equations involve higher order differential equations still remained unsolved [9]. There are the online and the offline generation methods [9]. The first one, should be done in real time and requires a high computational effort. On the other hand, a popular way to solve this problem is to resort to offline optimization techniques. In this paper it is used the model parameters and actuator inputs that lead to fully open-loop stable walking motions based on a simplified robot model to increase stability (Figure 2).

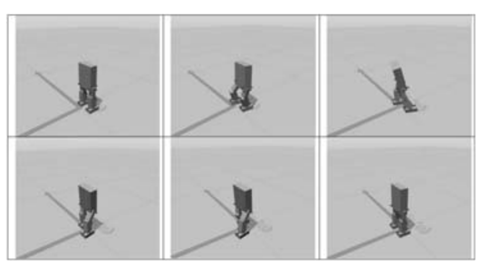

FIGURE 2. SimTwo Humanoid Simplified model walking.

Simulator receives the gait parameters from Matlab, runs it and returns the humanoid traveled distance through UDP network packet for each optimization iteration.

The next section briefly describes the main ideas behind the used optimization methods.

OPTIMIZATION METHODS

Two well known optimization methods were used in the humanoid gait planning: the Stretched Simulated Annealing and the Genetic Algorithm.

The SSA method belongs to the class of the multilocal optimization methods. The SSA method solves, in each iteration, a global optimization problem using the simulated annealing (SA) algorithm. The SA is a point-to-point stochastic algorithm that does not require derivative information and is able to guarantee convergence to a global solution with probability one. In each iteration of the SSA method, the global problem is transformed using a function stretching technique [10].

The GA method is a search heuristic that mimics the process of natural evolution of species from Darwin [11]. The GA method starts with a set of solutions called population, the population size is preserved through each generation and in each generation. The objective function is evaluated in each population member and they are selected according to their objective value. Those selected (maximum value) will reproduce up randomly, which occurs according to the genetic operators such as mutation and crossover. The evolution process is repeated until the stopping criterion is satisfied [12].

COMPARATIVE STUDY RESULTS

The numerical results were obtained using a Inter Core i7-2600 CPU 3.4 GHz with 8.0 GB of RAM.

For the optimization procedure, the input data is presented as a square matrix with dimension equal to 10. The initial approximation is defined as

$$x_0 = \begin{bmatrix} -26 & 15 & -10 & -55 & 25 & -10 & 10 & 10 & 35 & 10 \\ -26 & 15 & -10 & -30 & -10 & -10 & 10 & 10 & 45 & 10 \\ -26 & 25 & 10 & -30 & 0 & 10 & 10 & -10 & 45 & -10 \\ -40 & 40 & 10 & -15 & 5 & 10 & 15 & -10 & 25 & -10 \\ -55 & 25 & 10 & -15 & 5 & 10 & 45 & -10 & 25 & -10 \\ -30 & -10 & 10 & -15 & 5 & 10 & 45 & -10 & 15 & -10 \\ -30 & -10 & 10 & -40 & 30 & 10 & 45 & -10 & 15 & -10 \\ -30 & -5 & -10 & -40 & 30 & -10 & 40 & 10 & 15 & 10 \\ -30 & 0 & -10 & -45 & 33 & -10 & 35 & 10 & 20 & 10 \\ -30 & 0 & -10 & -55 & 10 & -10 & 35 & 10 & 50 & 10 \end{bmatrix}$$

that was obtained through empirical analysis. The matrix x_0 presents the initial gait for 10 joints (lines) and for 10 time instants (columns).

The upper and lower limits are defined using x_0, as $l = x_0 - \alpha 1_{10}$ and $u = x_0 + \alpha 1_{10}$, where $1_{10} \in \mathbb{R}^{10\times 10}$ is a matrix with coefficient one in all positions. The step distance of the humanoid robot when considered the input variable x_0 is $f(x_0) = 0.089202$ m.

In SSA method the parameters δ_1, δ_2, κ and α were fixed as 10^2, 1, 10^{-3} and 2, respectively. In the GA method it was consider the population equal to 20 individuals. For both methods, the maximum number of function evaluations was set to 6000 and the maximum number of iterations was set as 4000. Since both methods are stochastic, each problem was solved five times and the numerical results presented in the following table are average values over the runs.

The Table 1 presents the method used, the best value obtained in all runs, the average of the function evaluations, FE_A, and the time average, T_A, in seconds.

TABLE 1. Comparative study: SSA versus GA.

Method	Optimum value	FE_A	T_A (s)
SSA	1.741E-01	6000	2.7282E+04
GA	1.481E-01	1525	6.8200E+03

The Figure 3 presents the optimization results in a graphical way for some iterations.

Both methods were able to improve the initial solution. The SSA method was able to identify a better solution than the GA method. The GA method converges prematurely to a local solution, and does not identify the global solution.

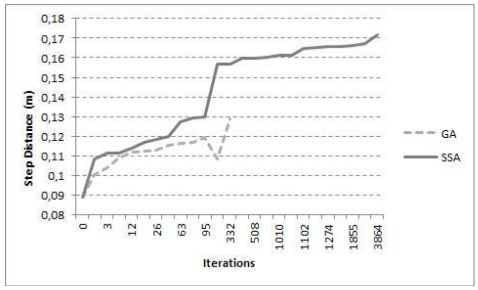

FIGURE 3. Comparative study: SSA versus GA.

CONCLUSIONS AND FUTURE WORK

In this paper a comparative study between the Stretched simulated annealing and the Genetic Algorithm optimization methods for creating the gait planning of humanoid robots was presented. For that purpose, tests were conducted on the personalized simulator SimTwo, a robot simulator that is capable of simulating user-defined robots in three-dimensional space with physical model based on rigid body dynamics. With 6000 functions evaluations the SSA algorithm identifies the best solution for the optimization problem. The GA algorithm identified a local solution and stopped prematurely. With the SSA algorithm it was possible to improve 95% and the GA was capable of improve 66%.

Once this approach is validated, the implementation of a complete model including arms and head (increasing dimension to 230) and the gait transfer to the real robot is a promising future work.

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