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# Quadruped Robot Locomotion using a Global Optimization Stochastic Algorithm

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**Abstract.** The problem of tuning nonlinear dynamical systems parameters, such that the attained results are considered good ones, is a relevant one. This article describes the development of a gait optimization system that allows a fast but stable robot quadruped crawl gait. We combine bio-inspired Central Patterns Generators (CPGs) and Genetic Algorithms (GA). CPGs are modelled as autonomous differential equations, that generate the necessary limb movement to perform the required walking gait. The GA finds parameterizations of the CPGs parameters which attain good gaits in terms of speed, vibration and stability. Moreover, two constraint handling techniques based on tournament selection and repairing mechanism are embedded in the GA to solve the proposed constrained optimization problem and make the search more efficient.

The experimental results, performed on a simulated Aibo robot, demonstrate that our approach allows low vibration with a high velocity and wide stability margin for a quadruped slow crawl gait.

**Keywords:** Optimization algorithm, CPG, modular locomotion, rhythmic primitive, discrete primitive

**PACS:** 87.85.St

## INTRODUCTION

Robot locomotion is a challenging task that involves the control of a large number of degrees of freedom (DOF's). Several previous works, [1] proposed biologic approaches to generate and modulate gait locomotion of quadruped robots, combining biometric sensory information with motion oscillators such as Central Pattern Generators (CPGs).

There are still many open questions in the quadruped locomotion, considering learning gaits or gait optimization. The problem of finding the best possible locomotion is a problem currently addressed in the literature [2, 3, 4]. Usually optimization systems are applied to improve the performance of quadruped robot locomotion. Specifically, Aibo quadruped locomotion. Robocup is one of the motivation engines for these works.

In this work, we propose an approach to optimize a quadruped slow crawl gait, using Central Pattern Generators (CPGs) [5] and a genetic algorithm. The locomotion controller, based on CPGs, generates trajectories for hip robot joints [1]. These CPGs are modelled as coupled oscillators and solved using numeric integration.

The proposed CPG is based on Hopf oscillators, and allows to explicitly and smoothly modulate the generated trajectories according to changes in the CPG parameters such as amplitude, offset and frequency. In order to achieve the desired crawl gait, it is necessary to appropriately tune these parameters. In this work, these parameters are optimized using a GA [6]. Speed, vibration and stability are the evaluated criterions used to explore the parameter space of the network of CPGs to identify the best crawl pattern. Optimization is done online in a simulated ers-7 AIBO robot using Webots [7]. Note that the goal was not to achieve the highest possible velocity. Rather was to achieve the highest velocity for a slow, crawl gait, which has to respect a large duty factor. We have already addressed a slightly different but related problem in a preliminary experience using a genetic algorithm [8] and the electromagnetism-like algorithm [9]. In these works, we noticed that solving this problem requires a considerable computational effort. Notably because several constraints are imposed in this optimization problem. Thus, alternative techniques for handling constraints can make the search more efficient. In this work, several experiments on a simulated Aibo robot, are performed in order to compare the performance of two distinct constraint handling techniques embedded onto the GA. The experimental results, demonstrate that our approach allows low vibration with a high velocity and wide stability margin for a quadruped slow crawl gait. Better results were obtained by the tournament selection in terms of the evaluation criterion and the computational times.

**TABLE 1.** Parameter bounds

	$\mu_{FL}$	$O_{FL}$	$\mu_{HL}$	$O_{HL}$	$\omega_{sw}(\text{rad/s})$	$K_{FL}(^\circ)$	$K_{HL}(^\circ)$
<b>Upper</b>	3600	400	3600	1600	12	127	127
<b>Lower</b>	0.0001	-1600	0.0001	-400	1	-30	5

## LOCOMOTION GENERATION

In this work we address the crawl gait generation [1]. This is a slow symmetric gait (all the legs have the same duty factor). The rhythmic movements of each hip joint of a limb,  $i=(FL,FR,HL,HR)$ , are generated by a Hopf oscillator, given by

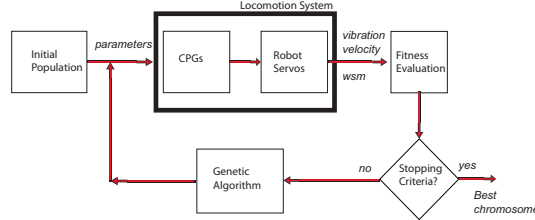
$$\dot{x}_i = \alpha (\mu - r_i^2) (x_i - O_i) - \omega z_i, \quad (1)$$

$$\dot{z}_i = \alpha (\mu - r_i^2) z_i + \omega (x_i - O_i), \quad (2)$$

where  $r_i = \sqrt{(x_i - O_i)^2 + z_i^2}$ , amplitude of the oscillations is given by  $A = \sqrt{\mu}$ ,  $\omega$  specifies the oscillations frequency (in  $\text{rad s}^{-1}$ ) and relaxation to the limit cycle is given by  $\frac{1}{2\alpha\mu}$ . This oscillator contains an Hopf bifurcation from a stable fixed point at  $(x_i, z_i) = (O_i, 0)$  (when  $\mu < 0$ ) to a structurally stable, harmonic limit cycle, for  $\mu > 0$ . The frequency ( $\omega$ ) allows an independent control of speed of the ascending and descending phases of the rhythmic signal, meaning an independent control of the stance  $\omega_{st}$  and the swing durations  $\omega_{sw}$ . We have four CPGs, one for each Hip joint. These four CPGs are coupled in order to achieve the limb coordination required in a walking gait pattern.

## OPTIMIZATION SYSTEM

We use a stochastic algorithm framework to search the optimal combination of the CPG parameters. A scheme of the optimization system is depicted in fig 1. Each chromosome consists in these 7 CPG free parameters: amplitude of the



**FIGURE 1.** Optimization Locomotion System

fore and hind limbs ( $\mu_{FL}, \mu_{HL}$ ); fore and hind limbs knee stance angle ( $K_{FL}, K_{HL}$ ); fore and hind limbs offset ( $O_{FL}, O_{HL}$ ) and swing frequency ( $\omega_{sw}$ ).

Genetic Algorithms (GA) are population based algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, selection, and crossover. In order to recombine and mutate chromosomes, the Simulated Binary Crossover (SBX) and Polynomial Mutation were considered, respectively. The performance of each chromosome and thus the resultant walk gait, is evaluated in terms of robot forward velocity ( $v$ ), robot body vibration ( $f_a$ ) and stability (WSM), as followed:

$$f = W_a * \frac{f_a}{f_{a,max}} + W_v * \frac{1}{v} * v_{min} + W_{WSM} * e^{-\frac{WSM}{WSM_{max}}}, \quad (3)$$

where  $W_a, W_v$  and  $W_{WSM}$  are the vibration, velocity and WSM weights, respectively. The search range of the CPG network parameters directly depend on the Aibo Ers-7 robot, and were set before hand as shown in Table 1.

In order to handle the simple boundary constraints, each new generated chromosome is projected component by component in order to satisfy boundary constraints. The problem has several simple boundary constraints (see Table 1)

**TABLE 2.** Performance of GA algorithm in the optimization system

Constraint-handling Technique	Fitness			Time (hours)		
	Best	Mean	SD	Best	Mean	SD
Tournament	0.2088	0.2817	0.743	0.7036	0.97206	0.4367
Repairing	0.2727	0.2973	0.0212	3.5350	4.0843	2.0975

as well as inequality constraints (for  $O_{FL}$ ,  $O_{HL}$ ,  $K_{FL}$  and  $K_{HL}$ ). In order to handle the inequality constraints, two approaches are implemented: a repairing method and the tournament based constraint method [10]. In the approach based on a repairing mechanism, any infeasible solution is repaired exploring the relations among variables expressed by the inequality constraints, i.e., the values  $O_{FL}$ ,  $O_{HL}$ ,  $K_{FL}$  and  $K_{HL}$  are repaired in order to satisfy the constraints. The second approach is based on the tournament based constraint method proposed by Deb [10] that is based on a penalty function which does not require any penalty parameter. For comparison purposes, tournament selection is exploited to make sure that: Therefore, the fitness function, in which infeasible solutions are compared based on only their constraint violation, can be expressed by:

$$F(x) = \begin{cases} f(x) & \text{if } g_j(x) \leq 0, \forall_j \\ f_{max} + \sum_{j=1}^8 |max(0, g_j(x))| & \text{otherwise} \end{cases} \quad (4)$$

where  $f(x)$  is the objective function given by Eq. 3,  $f_{max}$  is the objective function value of the worst feasible solution in the population and  $g_j(x)$  are the 8 inequality constraints to be satisfied. This approach can be only applicable to population-based search methods such as GAs. An important advantage of this approach is that it is not required to compute the objective function value for infeasible solutions.

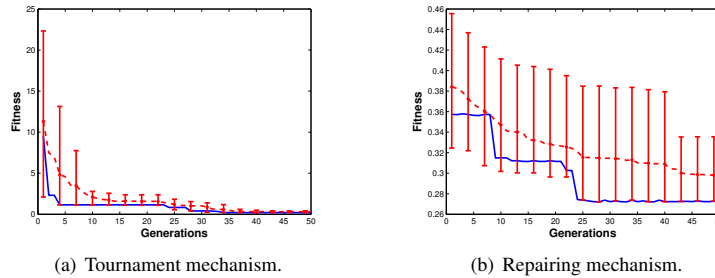
## SIMULATION RESULTS

In this section, we describe the experiment done in a simulated ers-7 AIBO robot using Webots simulator [7]. The ers-7 AIBO dog robot is a 18 DOFs quadruped robot made by Sony. The locomotion controller generates trajectories for the hip and knee joint angles, that is 8 DOFs of the robot, 2 DOFs in each leg. At each sensorial cycle (30 ms), sensory information is acquired. Each chromosome is evaluated during 12 seconds. We apply the Euler method with 1ms fixed integration step, to integrate the system of equations. In our implementation, we depict results when a population was established with 50 chromosomes and a preset number of 50 generations was set. Each experiment is run 10 times because this is a stochastic-based method. The generated gaits have a fixed duty factor  $\beta = 0.75$  and a relative phase  $\phi_{LH} = 0.75$ . Table 2 contains the Best, Mean and standard deviation (SD) values of the solutions found (in terms of fitness function and time) over the 10 runs, for the two constraint-handling technique used. The best individual with the tournament mechanism has a fitness value of 0.2088 and the best individual with the repairing mechanism has a fitness value of 0.2727, that was achieved at generation 50. When comparing stochastic algorithms, the most important is the metric in terms of average values, since it reports the central tendency of the results over the runs. By analysing table 2, we can see that the tournament selection method is the least time consuming algorithm and with the best mean fitness value. We also remark that the tournament method had 0.97206 hours as average time, while the repairing method had 4.0843 hours as average time. This difference is justified for not being necessary to compute the objective function value for infeasible solutions. The Figures 2 show the best (solid line) and mean (dashed line) fitness function evolution of the 30 runs for the tournament and repairing mechanism, respectively. Minimum and maximum values over the 30 runs are represented by the error bars.

The velocity is  $0.0804(ms^{-1})$  and  $0.05098(ms^{-1})$  for the tournament selection and the repairing technique, respectively.

## CONCLUSIONS AND FUTURE WORKS

In this article, we have addressed the locomotion optimization of a quadruped robot that walks with a slow walking gait. A locomotion controller based on dynamical systems to model CPGs, generates quadruped locomotion. These CPG



**FIGURE 2.** Fitness evolution during 50 generations.

parameters are tuned by an optimization system. This optimization system combines CPGs and a genetic algorithm. Moreover, two constraint handling techniques were embedded in the genetic algorithm to solve the constrained optimization problem. Experiments were performed in the Webots robotics simulator. The aim was to compare the performance of the two constraint handling techniques according to the evaluation criterion and the computational times. The best results were obtained by the tournament selection. However, both techniques were able to obtain a set of parameters adequate for the implementation of a quadruped walking gait with low vibration, high stability margin and a velocity of  $0.0804(ms^{-1})$  and  $0.05098(ms^{-1})$  for the tournament selection and repairing mechanism respectively.

Currently, we are using other optimization methods such as evolutionary strategies and electromagnetism algorithm, as well as other fitness functions. We will extend this optimization work to address other locomotion related problems, such as: the generation and switch among different gaits according to the sensorial information and the control of locomotion direction.

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