A(very) short introduction to walking robots

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Released at 21 October 2004
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Related to walking robots

I have found that when talking of walking robots, we can find three main types of gaits:
1) Static gait: the robot is always stable at any position of the feet
2) Dynamic gait: the robot achieves stability by using other forces like velocity or inertia
3) Passive gait: not really understood... Is like a dynamic gait without feedback

Probably, in our case with Aibo, the gait to be generated will be a static gait, since Aibo is very stable with four legs, and may not have enough velocity or inertia to achieve dynamic gaits.

To generate any of those types of gaits there are three main methods:
1) Methods based on trajectory: Those perform all kind of calculations to obtain the correct trajectory of every joint at every moment. Are very processor consuming. An example are methods using the Zero Moment Point (ZMP)
2) Methods based on heuristics: They also perform all kind of calculations to obtain the correct trajectory, but calculations do not use equations but heuristic methods like Genetic Algorithms (GA). An example is the Virtual Model Control method
3) Methods based on Central Pattern Generators (CPG): based on neurophysiology studies, they try to implement CPGs found in vertebrates to generate walking patterns. CPGs generate a kind of rhythm signal that makes muscles coordinate to generate the gait movement. In order to improve stability, Dr. Ijspeert proposes to add a reflex system, so CPGs would generate the gait and a reflexes system would maintain the posture in front of changes to the environment that may affect the walking.

CPGs systems seems to be the most promising one. CPGs are generators of a rhythm signal that may control the movement of the robot while walking. CPGs are made of neural non-lineal oscillators, and this theory was proposed by Matsuoka at 1987. It has been found CPGs in some vertebrates like cats or monkeys, and it is thought that a similar mechanism will be found in humans.
What is not clear to me is how are CPGs created artificially. I know that to create a CPG you must decide how many oscillators will the system have (from biology, one per each DOF), how are oscillators going to be coupled, and how are the oscillators going to control the motors. Very good in theory but I don't know how to do it in practice yet (suggestions?).

I have understood that the generation of gaits in some vertebrates are composed of two parts: one part located in the spinal cord that generates the basic rhythmic patterns necessary for locomotion (CPGS), and a second part located somewhere in the brain that sends commands to the spinal cord to order one type or another of gait. This command is very simple and does not specify how the gait must be performed, just high level commands to stop or start the gaits, speed and direction. In fact, it is said that those commands cannot command the spinal cord but just to make suggestions to it.

I don't know how CPGs are constructed but it looks to me that they must look similar to our architecture. I think that our implementation of the walking Aibo will go more on this direction than in methods based on trajectory or heuristics (but heuristics will also be

used). About this subject, I found Richard Reeve's PhD thesis (University of Edinburgh, 1999) the most interesting document related to our work. His thesis follows a similar path to that of us, and gives very good ideas and results, at the same time that it gives indications for generation of new results that we will have to implement. He also includes experiments about high order commands commanding the CPGs. Also, a lot of bibliography on it.

Based on what I have explained before, and where I want to go (generate Aibo's gait using the distributed architecture of neural nets), and after having read some papers, I have classified the bibliography in the following sections:

1) About generation of gaits in robots (in general)

- A.J. Ijspeert. 'Locomotion, Vertebrate'. The handbook of brain theory and neural networks, 2001, MIT Press
- R. Reeve. "Generating Walking Behaviours in Legged Robots", 1999
- G. Taga. "A model of the neuro-muscular-skeletal system for anticipatory adjustment of human locomotion during obstacle avoidance". Biological Cybernetics, 78(1),9-7, 1998
- V. Zykov, J. Bongard and H. Lipson. "Evolving Dynamic Gaits on a Physical Robot", 2004
- K. Sims, "Evolving 3D Morphology and Behavior by Competition", 1994
- J.C. Gallagher, R.D. Beer et al, "Application of evolved locomotion controllers to a hexapod robot", 1996
- C.W. Seys and R.D. Beer, "Evolving Walking: The Anatomy of an Evolutionary Search", 2004
- K. Sims, "Evolving Virtual Creatures", 1994

2) About CPGs

- S. Grillner, "Neurobiological bases of rhythmic Motor Acts in Vertebrates", 1985
- B. Calancie et al. "Involuntary stepping after chronic spinal cord injury. Evidence for a central rhythm generator for locomotion in man", 1994
- A. Ijspeert, "A connectionist central pattern generator for the aquatic and terrestrial gaits of a simulated salamander", 2001
- A. Ijspeert and J-M. Cabelguen, "Gait transition from swimming to walking: investigation of salamander locomotion control using nonlinear oscillators", 2003

3) About generation of gaits in quadrupeds

- H. Kimura, S. Akiyama and K. Sakurama. 'Realization of Dynamic Walking and Running of the Quadruped Using Neural Osicllator'. Autonomous Robots 7(3),247-258, 1999
- H. Kimura, Y. Fukuoka and K. Konaga. 'Adaptive Dynamic Walking of a Quadruped Robot by Using Neural System Model'.
- J.J. Collins and S.A. Richmond, " Hard-wired Central Pattern Generators for Quadrupedal Locomotion", Biological Cybernetics 71, 1994

3b) About generation of gaits in Aibo

- Chernova and Veloso, "An Evolutionary Approach to Gait Learning For Four-Legged Robots", IROS 2004
- A. Billard and A. J. Ijspeert, "Biologically Inspired Neural Controllers for Motor Control in a Quadruped Robot", 1999
- T. Rofer, "Evolutionary Gait-Optimization Using Fitness Function Based on Proprioception", Robocup Workshop, 2004
- G.S. Hornby et al, "Autonomous evolution of gaits with the Sony quadruped robot", 1999
- G.S. Hornby et al, "Evolving robust gaits with Aibo",1998

4) About generation of gaits in humanoids

- Arakada and Fukuda, "Natural motion generation of biped locomotion ...", 1997
- A. Calvitti and R. Beer, "Analysis of a Distributed Model of Leg Coordination I. Individual Coordination Mechanisms"
- A lot of information in the MsC Thesis and projects of M. Salzmann and S. Mojon from the EPFL, and in the MscThesis of Yariv from the University of Edinburgh. 2003-2004

5) About special ANNs models for the generation of gaits

- R.D. Beer, "On the dynamics of small continuous-time recurrent networks", 1995
- G. Taga, "A model of the neuro-musculo-skeletal system for human locomotion", 1995
- P. Wallen et al, "A computer based model for realistic simulations of neural networks. II. the segmental network generating locomotor rhythmicity in the lamprey", 1992