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Diploma Thesis Proposal

Humanoid Robot Simulation and Walking Behavior Development in the Spark Simulator Framework

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April 2005

Contents

1 Motivation

The idea for this thesis grew out of the authors' work as a member of the RoboCup Simulation League team *RoboLog* (see e.g. [Murray *et al.*, 2002, Amor *et al.*, 2003]) at the Artificial Intelligence Research Group, University of Koblenz in Germany, and a discussion about the future of the Simulation League itself which took place at the RoboCup-2004 in Lisbon, Portugal.

The *RoboLog* team has worked on agents both for the 2D and the 3D simulator, and took part in several RoboCup competitions so far. Besides that, members of the team also developed the new 3D simulation platform (see [Kögler and Obst, 2004, Obst and Rollmann, 2004]), which is used for the official competitions since RoboCup-2004. While the 3D simulator was introduced successfully at this event, the development is still in its beginnings and many changes and additional features can be expected in the near future.

During a discussion amongst members of the Simulation League community at the RoboCup-2004, it became clear that a majority of researchers would like to push the 3D simulation towards simulating humanoid robots. It was considered by many as a necessary step towards the declared goal of the RoboCup initiative [Kitano *et al.*, 1997, Kitano and Asada, 2000]: to built a team of fully autonomous humanoid robots able to beat the human soccer champion by the middle of the 21st century. This thesis is aimed to contribute to these efforts by providing some of the first steps into the direction of humanoid robot simulation.

2 Goals

The goal of this thesis will be to extend the current 3D simulator of the RoboCup Simulation League (which uses the generic building blocks of Spark [Obst and Rollmann, 2004]) in order to simulate a humanoid robot. Furthermore, a controller for a walking motion of the simulated robot will be developed, using evolutionary algorithms. This will serve both as a proof-of-concept that the simulator can indeed be used for research on humanoid robots, as well as a starting point for the development of more controllers and behaviors that can be used in the actual soccer simulation. If time permits, an evaluation of the simulation accuracy could could be carried out, using the developed behavior on a real robot of the same type as the simulated one.

2.1 Robot Simulation

For the robot model to be simulated, several choices were possible. A robot could, for instance, be designed and modeled from scratch. This would have the advantage of having full control over the design process and the resulting properties of the robot. However, designing a humanoid robot that can actually perform dynamically stable walking is a very difficult and time consuming task of its own. Therefore, it seemed reasonable to simulate an existing robot model, namely the HOAP-2 robot from Fujitsu

Automation Ltd. The reasons why this model was chosen in particular are that there is already work available on which it is possible to build on, and also because the author has access to a real robot of this type at the time during which the project is to be carried out[1]. This should facilitate tweaking and verifying the simulation model.

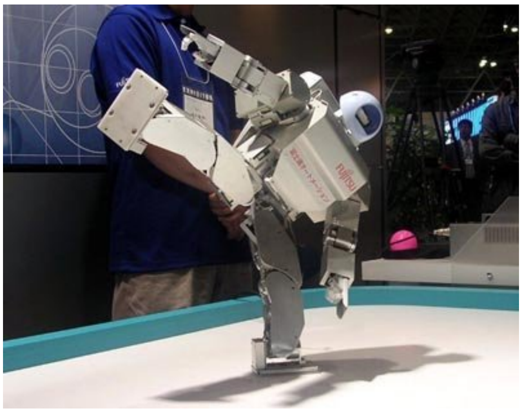

Figure 1: The Fujitsu HOAP-2 robot

In his master's thesis [Cominoli, 2005] at the Swiss Federal Institute of Technology, Pascal Cominoli modeled the HOAP-2 robot for the commercial robot simlator *Webots* [Michel, 1998] and implemented different movement controllers for it. The author had email correspondence with P. Cominoli and was granted permission[2] to use the file he created for the *Webots* simulation. The format of the file is similar to a VRML97 file, although not all node types from the standard have been implemented, and some additional ones have been added. The first step for the setup of the robot in this work will then be convert the information in the the *Webots* file into a *RubySeceneGraph* structure as used in the RoboCup 3D simulator.

After this has been done, the physical parameters of the robot might have to be tweaked, and the different sensors (force sensors in the feet, encoders in all the joints, gyroscope, accelerometer, and a camera) and actuators of the robot (motors for all the joints) have to be implemented for the simulation.

2.2 Walking Controller Development

Implementations of biped behaviors including walking motions are currently mainly based on two approaches. The first one is model based using *Zero Moment Point* (ZMP) control (e.g. [Kajita and Tani, 1996]) or an inverted pendulum model (e.g. [Yamaguchi *et al.*, 1996, Sugihara *et al.*, 2002]). Desired joint trajectories are planned and the system controls the motors to follow them. However, a precise dynamics model of both the environment and the robot are needed to generate a stable walking behavior with these methods.

[1]The author wishes to thank professor Minoru Asada for his support and for the opportunity to work and learn at his laboratory at Osaka University

[2]The author whishes to thank Pascal Cominoli for granting permission to use his material in this thesis

The second approach uses interconnected neural circuits, so called *Central Pattern Generators* (CPGs), to generate walking motions similar to the way neurophysiological studies indicate they work in many animals [Grillner, 1985]. The CPG is comprised of several interconnected subnetworks which can produce (stable) oscillations and influence each other through the mutual connections. The output of the oscillators can be interpreted as a force to be sent to the motor controller of the robot, or as a desired joint angle. No dynamics model of the robot or the environment is needed for this method. Instead, the walking motion is stabilized through the interaction of the neural structures in the CPG while providing possibilites for adaptation to changes in the environment [Fujii *et al.*, 2001, Taga, 1998, Fukuoka *et al.*, 1999]. It is, however, rather difficult to determine the appropriate parameter settings for the oscillator network in the CPG in order to generate a suitable pattern for walking control. Therefore, evolutionary computation methods are often used to optimize the parameters (cf. [Shan *et al.*, 2000] or [Reil and Husbands, 2002]).

This work will adopt the second approach, namely, using a genetic algorithm (GA) [Goldberg, 1989, Holland, 1975] to optimize a CPG for the walking motion of the simulated humanoid robot. At this point, however, several details of the implementation are yet unclear and have to be investigated further:

- **Neural oscillator model** Several models exist and have been applied successfully. It seems worthwile to try using Matsuoka's model [Matsuoka, 1987] and the model proposed by Ijspeert and Cabelguen in [Ijspeert and Cabelguen, 2003]. The first model was shown to be suitable to generate patterns for bipedal locomotion in different works [Taga *et al.*, 1991, Shan *et al.*, 2000, Ishiguro *et al.*, 2003]. The second model was applied to a simulated humanoid robot in [Mojon, 2004] and could produce a pattern that enabled the robot to walk at a speed of 1.5 km/h. Continuous Time Recurrent Neural Networks as described in [Beer, 1995, Beer and Gallagher, 1999, Chiel *et al.*, 1999] would be another possibility.

- **Interneuron connections in the CPG** Different controller layouts have been used in the past (cf. [Taga *et al.*, 1991, Mojon, 2004]). It has to be investigated which layout is the most suitable for the task in this thesis. Another possibility would be to include the morphology of the interneuron connections in the evolution process. This would aleviate from the work of handcoding the network design, but would also result in a much larger genome, affecting the time to convergence of the GA. Possibly, also a rather sophisticated encoding would have to be used for the chromosomes.

As the evaluations of the individuals in the genetic algorithm have to be evaluated in a computationally expensive simulation, it seems to be reasonable to make use of *informed operators* as described in [Rasheed, 1999] and [Rasheed, 2000]. These operators are biased towards the more favorable solutions in the search space and can lead to desirable solutions much faster than simple uniform crossover and mutation operators, especially if only a small number of generations can be evaluated (as in this case). However, to avoid getting stuck in a local, suboptimal solution the parameters of the GA (like mutation rate, crossover rate, selection scheme, replacement policy, and the fitness function) have to be chosen carefully. Active diversity monitoring and management might be necessary.

3 Related Work

- Selforganized control of bipedal locomotion by neural oscillators in unpredictable environment [Taga *et al.*, 1991]
- A connectionist central pattern generator for the aquatic and terrestrial gaits of a simulated salamander [Ijspeert, 2001]
- Gait transition from swimming to walking: investigation of salamander locomotion control using nonlinear oscillators [Ijspeert and Cabelguen, 2003]
- Evolution of central pattern generators for bipedal walking in a real-time physics environment [Reil and Husbands, 2002]
- Evolution and analysis of model CPGs for walking [Beer and Gallagher, 1999, Chiel *et al.*, 1999]
- Generating walking behaviours in legged robots [Reeve, 1999]
- Using nonlinear oscillators to control the locomotion of a simulated biped robot [Mojon, 2004]
- Design of Central Pattern Generator for Humanoid Robot Walking based on Multi-objective GA [Shan *et al.*, 2000]
- Neuromodulated Control of Bipedal Locomotion Using a Polymorphic CPG Circuit [Ishiguro *et al.*, 2003]
- A Bipedal walk using a Central Pattern Generator [H.Inada and K.Ishii, 2004]
- Three Dimensional Bipedal Stepping Motion using Neural Oscillators – Towards Humanoid Motion in the Real World [Miyakoshi *et al.*, 1998]
- A Motion Learning Method using CPG/NP [Nagashima, 2003]

4 Time Schedule

Task	**Weeks**
Literature review and planning	6
Implementation of the robot model	6
Implementation of the evolutionary algorithm	6
Evaluation of the developed controller	2
Final documentation	4

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This renders simulations and simulation models more accessible to a general-public, by reducing the simulation model deployment complexity.Â In the case of a humanoid robot, for example, V-REP can handle leg movements by (a) first calculating inverse kinematics for each leg (i.e., from a desired foot position and orientation, all leg joint positions are calculated); and then (b) assigning the calculated joint positions to be used as target joint positions by the dynamics module.Â simulator, and their task definitions directly attached to simulation models, then models become extremely portable: distribution of a simulation model to a different machine or platform is done via a single model file; there is no need to distribute, recompile, install or reload a plug-in. The simulator has been forked and used to control different mobile robots, including a Roomba2 from iRobot. Likewise, please feel free to fork the project and improve it.Â Behavior-based robotics software was proposed more than 20 years ago and itâ€™s still a powerful tool for mobile robotics. As an example, in 2007 a set of behaviors was used in the DARPA Urban Challengeâ€”the first competition for autonomous driving cars!Â Again, we have a specific sensor model in this Python robot framework, while in the real world, sensors come with accompanying software that should provide similar conversion functions from non-linear values to meters. Determining the position and heading of the robot (together known as the pose in robotics programming) is somewhat more challenging. Finally, the simulated robot is a rigid robot with six degrees of freedom that can move and rotate freely in the sagittal plane. 4 Figure1A: Algorithm structure of the simulation Figure1b: Model of the robot. We note that each revolute joint is controlled by a servo module and the ground contacts as well as the frictions forces are simulated while the foot impacts the ground.Â 12 Conclusion and Future Works This paper proofs the accessibility for any scientists to the simulation of walking humanoid robot without any mathematics or physic background relative to this topic. The method and validation of this simulation are detailed along this paper.