Iterative Product Engineering: Evolutionary Robot Design

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Abstract

This paper discusses a low-tech method for evolutionary robot design. Two aspects are detailed: how apt is the evolutionary approach in the robot simulation package MorphEngine[1] to generate behaviors for robots that seem 'unnatural' from the human point of view; and how useful is artificial evolution in general to support the engineer in finding and controlling gaits based on emergent dynamics (especially passive dynamics) through the exploitation of the physical environment.

1 Introduction

In our research we explore ways of simultaneously developing the morphology (sensors, actuated and passive limbs) and the controller of a mobile robot which contrasts with the more traditional way of first designing the physical shape and then thinking about the controller.

The ideal principle of natural growth is still unmatched in robotics and in the real world it is often very hard to design, compute and control complex structures that consist of several interdependent parts - especially if they make use of passive dynamics or if no similar structures can be found in nature.

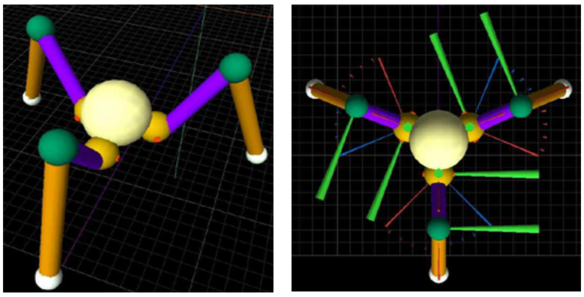
To tackle theses problems, a highly iterative method was used to build a relatively simple monkey-like robot through inspiration drawn from human engineering, evolutionary exploitation of the physical environment and the resulting optimization of its locomotion pattern in simulation. Eventually this pattern could be transferred to reality.

The design, simulation and construction of the robot was completed in under seven weeks.

2 The Inspiration-Factor

To initially explore the behaviors of morphologies not found in nature, a symmetric three-legged creature was built in simulation, since any biological occurrences of tripedal locomotion are unknown to the author.

The evolutionary algorithm evolved a control structure for the agent (by optimizing the weight matrix of an ANN connecting sensors to motors) that was well adapted to its specific morphology. The result was a successful locomotion pattern[2] that allowed the creature to follow a randomly placed light source.

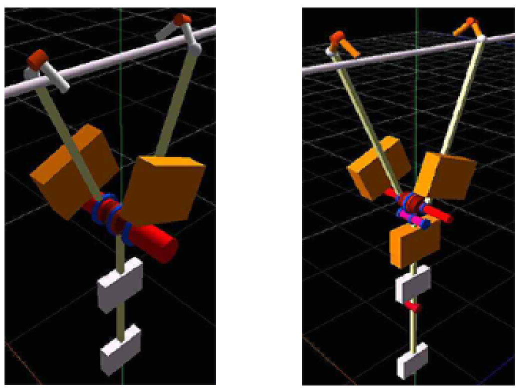


3 legged creature that successfully follows a light source: the green cones indicate the joint normals.

3 The Design of a Monkey-Robot

The transfer of observed, simulated behaviors to a real robot was tested with the fast and cheap implementation of a simple brachiating robot that takes advantage of the dynamics of an inverted pendulum for successful locomotion on a steel rope.

Several classes of monkey-like morphologies were engineered and implemented in the simulation environment of MorphEngine. The morphologies differed mainly in the number of actuated joints.



Above: Two examples of different monkey morphologies.

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[1]Development Tool by Josh Bongard: http://www.ifi.unizh.ch/ailab/people/bongard/MorphEngine/

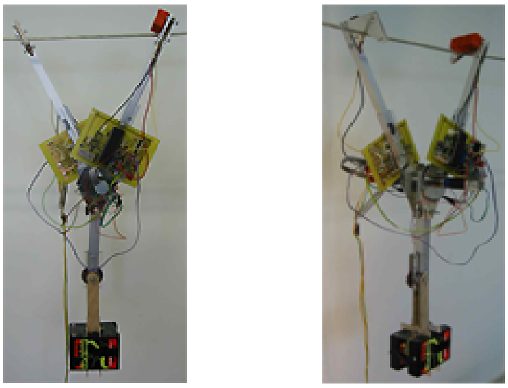
[2] Videos available at http://n.ethz.ch/student/fdominic/SP2002.html

Then artificial evolution was used to find a morphology that showed a promising locomotion pattern. Variants of the chosen morphology were engineered with differing numbers and placements of actuated and passive joints, and sensors in order to improve the robot's performance.

Eventually a morphology was chosen that was simple but interesting enough to be implemented as a real-world prototype within 1-2 weeks.

Several iteration steps between hardware considerations, the translation of these boundary conditions into simulation parameters, and the selection of a final morphology influenced by both simulation and hardware considerations had to be made.

Eventually, the mechanical prototype was built in three days; electronics were added during the following week.



Above: Photographs of the actual robot.

Finally the real hardware parameters and mass distribution were transferred into simulation again in order to exploit the physical properties of both the robot and the environment correctly (fine tuning).

The locomotion pattern observed in simulation had to be interpreted and programmed on the prototype, since the direct transfer of a situated ANN is still a technological challenge and was beyond the scope of our approach.

The result was a real-world prototype robot (based on the cross-inspired design) with a successful locomotion pattern similar to the one evolved in simulation that uses the dynamics of a passive inverted pendulum[3].

4 Discussion

There are several differences between the locomotion pattern of the virtual agent and the prototype. They have to do with known shortcomings of the simulation accuracy in MorphEngine (which is constantly being improved) mainly in regards to material properties (surface structure, friction, stiffness), actuator forces, spring parameters and noise.

Interestingly, one flaw helped to compensate for another: the prototype was brachiating on a rope consisting of twisted steel wires coated with thin rubber while in simulation a perfectly stiff bar was used. The result was a different quality of friction and a dynamic response of the flexible rope. The significantly higher friction between claws and rope in the real world demanded a more dynamic swinging behavior than observed in simulation (to free the arms) by using the whole body mass to gain momentum. This was possible due to the inaccurately simulated motor power which turned out to be much stronger in reality.

A drawback was the use of a programmed computer chip instead of an ANN.

Having no possibilities for a direct transfer yet, the question arises, how well a resulting locomotion pattern in general can be understood and interpreted by the human engineer. It worked well in this relatively simple case of a brachiating robot, but it is not clear whether this approach will work for more complex patterns when the interactions are no longer obvious and parallel processing would be required for real time performance.

5 Conclusions

After looking at the solution the algorithm came up with it might seem that it was obvious and the way how the physical properties of the robot and the environment were exploited was to be expected. This might be true in this relatively simple case. However, we think that the solutions found by evolution are often non-obvious or simpler (cheap design) then what an engineer or roboticist would think of without prior knowledge of the evolutionary solution and that such a tool may be of a great benefit when it comes to designing and rapidly evaluating new solutions for a complex structure with many moving parts and complex mass distributions (for a similar approach see [1]).

The results presented are promising, yet there are many more steps to be done in order to prove their significance and to improve the design tool for fast low-tech robot implementations.

6 Visions

Merging methods for digital mockup that are based on evolution in a high-level simulation environment with modular components[2],[3] that might be automatically manufactured and assembled[4] may lead to the perfection of automated rapid prototyping for robust, adaptive and 'intelligent' agents.

References

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