Explorations in evolutionary humanoid robotics.

Malachy Eaton
Department of Computer Science and Information Systems,
College of Informatics, University of Limerick, Ireland
email: malachy.eaton@ul.ie

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Abstract:

The field of evolutionary humanoid robotics is a branch of evolutionary robotics specifically dealing with the application of evolutionary principles to humanoid robot design. Previous studies [1,2] demonstrated the possible future potential of this approach by evolving walking behaviours for simulated humanoid robots with up to 20 degrees of freedom. In this paper we extend the work presented in the previous publications in several ways. We present preliminary results in the analysis of the behaviour of specific high-fitness evolved controllers and of the evolutionary process itself by examining the changes in diversity over time in the evolutionary process.
We then investigate the effect of minor alterations in robot morphology in walking ability. These include an alteration of the surface area of the robot in contact with the ground (foot size) and the effect of the immobilization of individual joint or joints in the robot. The latter study may be of potential future use in prosthetic design.
We explore also the possibility of the evolution of humanoid robots which can cope with different environmental conditions. These include reduced ground friction (ice) and modified gravitation (moon walking).
Finally we present initial results in the implementation of our simulated humanoid robots in hardware using the Bioloid robotic platform.

Introduction

The humanoid robot is simulated using the Webots mobile robot simulation package [3,4,5]. This system allows for the creation and modification of a large variety of robot types and robot worlds and it also allows for the creation of controllers for these robots. It also employs an accurate physics simulator allowing for the potential transfer of evolved robots from simulation to real embodied robots with little or no modification.
A number of keyframe values are defined and then passed to a separate existing utility; the sequence manager. These keyframes are values that must be reached at a specific point in the movement. An interpolation function in the sequence manager then fills in the motor values between individual keyframes. Every keyframe must be passed through in turn; once the final frame is reached the cycle repeats. A genetic algorithm is used to provide the values for the individual keyframes. The initial fitness function employed was a simple function mainly based on the robot remaining standing together with the distance traveled by the robot in a forward direction. Different varieties of walking behaviours were developed by the evolved robots and many observers commented of the lifelike nature of some of the walks developed.
Nolfi and Floreano provide a good introduction to the general topic of evolutionary robotics [6]. For a discussion on the general topic of the performance evaluation of bio-inspired embodied and simulated artifacts Eaton et al [7]. See references [8-11] for other work in this general area.

Experimental setup

In previous experiments it was found that the proportion of the maximum range of movement allowed to the robot for each joint was an important factor in evolving successful
Initial experiments placed no restriction on the range of movement allowed and walks did not evolve unless the robot was restricted to a stooped posture and a symmetrical gait, even then results were not impressive. In these experiments we include a value in the genome that specifies the fraction of the maximum movement range that is allowed for each joint. The genome length is 336 bits comprising 4 bits determining the position of the 20 motors for each of 4 keyframes; 80 strings are used

per generation. 16 bits define the fraction of the maximum movement range allowed. The maximum range allowed for a particular genome is the value specified in the corresponding to each motor divided by the number of bits set in this 16-bit field, plus 1, divided by 2. The genetic algorithm uses roulette wheel selection with elitism; the top string being guaranteed safe passage to the next generation, together with standard crossover and mutation. Two-point crossover is applied with a probability of 0.5 and the probability of a bit being mutated is 0.04. These values were arrived at after some experimentation.

In order to gain some insight into the evolutionary process we use a slightly modified version of the degree of population diversity described in by Leung et al [12]. This measure provides an easy to calculate and useful measure of population diversity: i.e. how alike the different strings in a population. We subtract this value from the genome bit length to produce our inverse degree of population diversity measure (IDOPD). This value will vary from 0 (no similarity in the strings) to a value corresponding to the genome length (all genomes have the same value at every bit location).

Evolution of walking in a robot with full functionality

Figure 1 shows the maximum and average fitness values together with the diversity measure described above, for a 20 degree of freedom robot with full functionality, and with 16 bits defining the maximum joint range. The 20 degrees of freedom comprise three for each leg (knee and two ankle joints), three for each hip, two for the back (twist and bend), two for each shoulder, and two elbow joints. The graph shows results as averaged over three runs and the fitness function is as described previously [2]. Diversity value is given on the right-hand vertical axis. The diversity value starts very low initially (corresponding to low similarity) as we would expect, as all strings are initially created at random. Sharp increases in the diversity measure correspond then to increases in maximum fitness as highly fit individuals attempt to make many copies of themselves. This is followed by a reduction thereafter as the genetic operators of mutation and crossover strive to maintain diversity in the population.

A fitness above about 800 should correspond to a reasonable walk in the forward direction, 1200 or above corresponding to stable walks in the forward direction. We see that the average maximum value peaks at around the value 3000, corresponding to a fast forward walk, with the knees kept fairly straight.

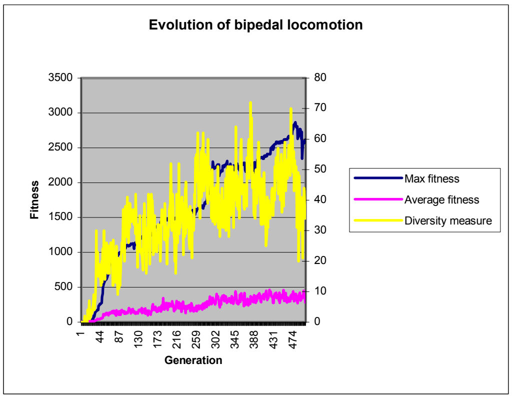

Figure 1. Evolution of walking in a fully functional robot

Effect of alterations in robot morphology

We now investigate the effect of restraining motion in part of the robot. We do this by immobilising the robots right knee joint, and both ankle joints. This might correspond to a situation of a person walking with a prosthetic leg. Figure 3 shows the results of this experiment again averaged over 3 runs

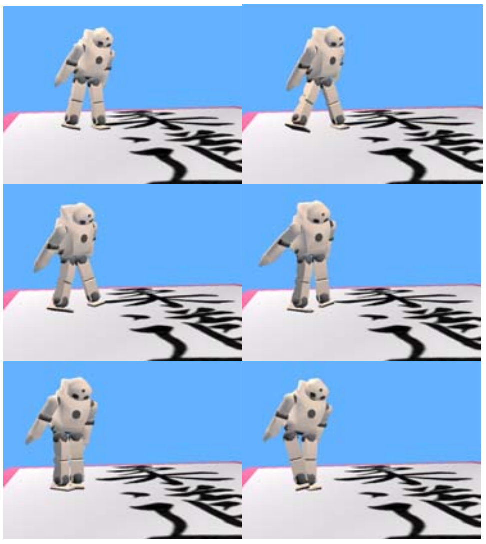

Figure 2. Walking with right leg restrained

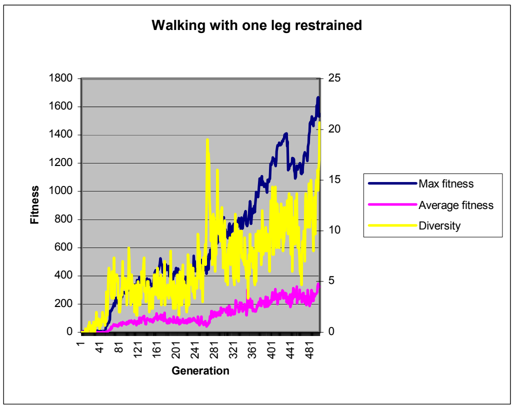

Figure 3. Average of three runs with right leg restrained

The robot learns to walk albeit with a reduced maximum fitness compared to the robot with no constraints. Figure 2 illustrates a typical walk which develops. The right (constrained) leg moves sideways and forwards, coming well off the ground, as the right arm moves backwards in a steadying motion. The left leg follows in a shuffling motion, and the cycle repeats. This pattern of motion proved surprisingly effective. We have also experimented with the alteration in foot size successfully producing walking with much reduced foot size but space precludes a detailed discussion of these results.

Effect of different environmental conditions

We are currently investigating the effect that different environmental conditions have on the evolution of walking (skating) behaviour; specifically walking on a surface with reduced friction, simulating icy conditions, and walking under conditions of reduced gravity. Fig. 4 shows the effect of reducing coulomb friction to 0.01, simulating the effect of very icy conditions. This is for a single run so the variation of diversity with fitness can be clearly seen. A quite effective sideways skating motion develops around generation 150. Further investigations are continuing to see what different patterns of skating develop. We have also started experiments in moon-like gravity producing walking, but far slower than in earth-like gravity; these results will be discussed in more detail in a later article.

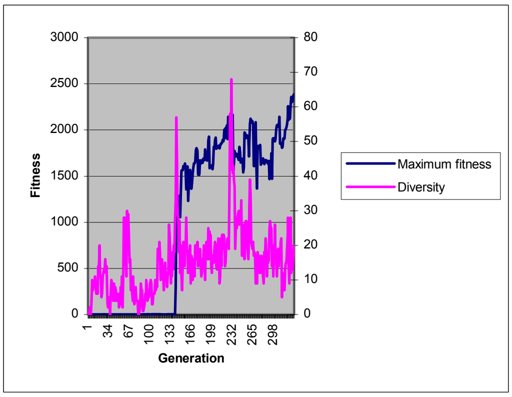

Figure 4. Results for reduced friction run

From simulation to reality

We are now beginning work to implement our simulated robots in the real world using the Bioloid robot platform. This platform is produced by Robotis Inc. Korea and consists of a CPU (CM-5), a number of senso-motoric actuators (Dynamixel AX12+) and a large number of universal frame construction pieces. Using this platform it is possible to construct a wide variety of robots, from simple wheeled robots to complex humanoid robots with many degrees of freedom. To gain initial experience with this kit we constructed a “puppy-bot” (Fig. 5) which can walk on four legs, avoid obstacles and perform several cute tricks. With this experience we then constructed the Bioloid humanoid robot (Fig. 6), which has 18 degrees of freedom in total. A modified version of this humanoid robot was used for Humanoid Team Humboldt in the RoboCup competitions in Bremen 2006. [13]

The Bioloid system has two pieces of software provided; the behaviour control programmer, and the motion editor. The behaviour control programmer programs the humanoids response to different environmental stimuli, while the motion editor describes individual motions based on the keyframe concept described in our work. We are currently building an accurate model of the Bioloid humanoid in Webots, and working on translating the information in our sequence control file into a format understandable by the Bioloid motion editor. Once this work is completed we hope to evolve walking, and other behaviours, in Webots using our accurate model, and then transfer the evolved behaviour directly to the Bioloid humanoid robot.

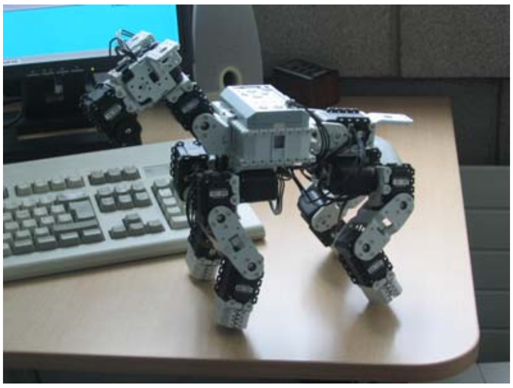

Figure 5. The “puppy-bot”

Figure 6. The Bioloid humanoid robot

Summary and future work

Using an accurate physics simulator a humanoid robot has evolved bipedal locomotion under a variety of different morphological constraints and under different environmental conditions. We have looked at the changes in diversity over the evolutionary process and at the behaviour of evolved robots. Finally we introduced the Bioloid robotic platform, which because of its modular and extensible nature is well suited to research in evolutionary robotics, and the 18 DOF Bioloid humanoid robot. Work is continuing in all of the areas described above, and particularly in moving our simulated humanoid robots into the real world using an enhanced (20 DOF) version of the Bioloid humanoid robot .

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