On Adaptive Robots

C. Torras
Institut de Robòtica i Informàtica Industrial (CSIC-UPC)
Gran Capità 2-4 (edifici NEXUS), 08034-Barcelona, SPAIN
e-mail: ctorras@iri.upc.es
http://www-iri.upc.es/people/torras

1 Introduction

Why are robots still confined to factory floors and research departments? Will they ever step out and be part of our everyday lives? Aside from ethical considerations and marketing strategies, there are technological reasons that explain why the use of robots is not as widespread as some envisaged they would be by now. At the risk of oversimplification, let me state that the Achilles heel of current robots is their lack of adaptivity, at all levels. This capability is dispensable in well-engineered environments, and thus we have very performant robots in manufacturing lines, but it is a *sine qua non* when tasks are to be carried out in non-predefined worlds.

In this sense, the biological world –where adaptivity is crucial for survival– constitutes a very good source of inspiration for robotics researchers, since it provides existence proofs of many adaptive mechanisms that do function. However, caution must be taken, because the best natural solution may not be the best artificial one (Simon 69). Wheels, wings and calculators have often been mentioned as examples of artificial solutions considerably different from their natural counterparts, and more performant according to certain criteria. The resources available to engineering design depart a lot from those in nature, and not just when it comes to materials, but also in the number of instances and spendable time.

With this note of caution in mind, i.e., accepting that biological plausibility in itself adds no special value from an engineering viewpoint, it is safe to look into natural adaptivity to get seed ideas that can be instantiated in a different way by artificial means.

2 Adaptive...

What exactly do we mean by adaptivity? What does it encompass? What is its range? By adaptivity we mean the capability of self-modification that some agents have, which allows them to maintain a level of performance when facing environmental changes, or to improve it when confronted repeatedly with the same situation. The term 'agent' above stands for a single cell, an organ, an individual or even a whole society, because, in the biological world, adaptivity occurs at several levels, each having a possible counterpart in the design of autonomous robots (Steels 95; Omidvar and van der Smagt 97; Sharkey 97; Ziemke and Sharkey 98).

At the cell level, several chemical and electrical mechanisms of **plasticity** have been discovered, some of which have been modelled and analysed within the Neural Networks field (Arbib 95), and later applied to adjust the parameters of robot sensors and actuators.

At the sensorimotor level, adaptation takes the form of an **association**, built through either classical or instrumental conditioning, as studied within the Behavioural Psychology field. Again, neural network models able to build relevant associations from experience (Hinton 89; Torras 95a) have been applied to the construction of robot sensorimotor mappings (Ritter et al. 92; Kröse 95; Torras 95b).

At a cognitive level, several **symbolic learning** strategies have been postulated, some of which have been mimicked within the field of Artificial Intelligence and later incorporated into learning robots (Kaelbling 93; Van de Velde 93; Dorigo 96; Mitchell et al. 96; Morik et al. 99).

Finally, at the species level, adaptation is attained through **evolution**. Genetic algorithms (Goldberg 89; Koza 92) and evolutionary computation (Higuchi et al. 97) are starting to be used to tailor robot genotypes to given tasks and environments (Husbands and Meyer 98).

In this special issue, instances of all four levels above can be found.

Notions such as receptivity fields and winner-take-all networks, coming from the first level, underlie the neural network algorithms used in several of the papers. Thus, McNeill and Card investigate four neural competitive algorithms for input clustering, and apply them to discriminate between simple visual patterns, while Valente et al. combine unsupervised and supervised neural procedures to determine suitable gripping points on an object.

The work by Lewis and Simó lies clearly at the sensorimotor level, since they use a neural network to build a perception-action mapping from experience. Specifically, this mapping adjusts stride length based on distance to the nearest obstacle, allowing a legged creature to step smoothly over obstacles.

Two papers combine elements from the sensorimotor and the cognitive levels. Trentin and Cattoni use a hidden markov model (HMM) to represent sequences of (unknown) robot positions, treating sensor measurements as the observed 'symbols' for restricting the hidden state. They use a recurrent neural network to encode the history-dependent HMM transition probabilities. Santos and Touzet propose an approach to tackle the exploration/exploitation dilemma by tuning the parameters of the reinforcement function, the underlying idea being to attain an ideal ratio between positive and negative reinforcement during learning. The approach is implemented by means of a neural associative memory.

Billard et al. investigate experimentally the influence of several factors on the performance of a team of learning robots. A probabilistic model is shown to match the experimental results with good accuracy.

An evolutionary procedure is applied by Filliat et al. to generate neural controllers for locomotion and obstacle-avoidance. To avoid high time demands, specific grammars are used to cut down the complexity of the developmental programs and the controllers, and a 'minimal simulation' approach is adopted. Following similar ideas, Grasso and Recce use a genetic algorithm to find appropriate values for the joint parameters involved in the rhytmical control of walking. Again, the developmental process is carried out in simulation.

3 ... Robots

Let us now turn to the other component of the special issue, namely robots. A robot is a multifunctional and reprogrammable mechanism able to move in a given environment. Three broad classes of robots can be distinguished on the basis of their mobility: *Robot arms* have a fixed base and their mobility comes from their articulated structure, thus operating on a bounded 3D workspace (Fu et al. 87). *Robot vehicles* move on 2D surfaces by using wheels or other similar continuous traction elements (Kortenkamp et al. 98). *Walking robots* are designed to move through rough terrains by using articulated legs (Raibert 86; Song 88). Of course, mixed possibilities do also exist like robot arms mounted on wheeled vehicles.

Representatives of these three classes of robots can be found in the papers included in this special issue.

Up to now, most work on adaptive robots has been carried out on robot vehicles, a tendency that also shows up here. Thus, Trentin and Cattoni use a vehicle built at their institute, that has two independent wheels plus a pivoting one, and is equipped with sixteen sonars carefully distributed around its body. A robot constructed with LEGO bricks hosts the four phototransistors and two photoresistors used by McNeill and Card in their visual discrimination experiments. A Khephera robot with eight infrared sensors is used by Santos and Touzet, and up to four such robots make up the teams on which Billard et al. perform their experiments in collective robotics.

However, walking robots are nowadays gaining attention, since they offer an even wider range of opportunities for adaptation, and three papers are devoted to them in this issue. Filliat et al. evolve neural controllers for a six-legged robot with two degrees-of-freedom (dof) per leg, and equipped with infrared and light sensors. Grasso and Recce work in a similar direction, but using a quadruped robot with eight joints. The work of Lewis and Simó considers only one leg, which adapts its rhythmic motion (derived from a given gait) when it needs to pass over an obstacle.

Finally, a robot arm with four dof is used by Valente et al. to demonstrate their neural gripping system. The three-fingered gripper contains six additional dof, controlled by just three actuators.

It must be noted that all the papers in this issue, but one, deal with real robots, something that was just a wish only a few years ago.

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