From Locomotion to Cognition: Cheap Design Approach to Adaptive Behavior

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In the traditional approach of robotics and artificial intelligence, one of the underlying implicit assumptions is that feedback control in the precisely modeled environment is the sole generator of intelligent behavior. The main body of research, therefore, has focused on computation, i.e. constructing a world model and making stepwise decisions of motor actions. A conceptual impact has been made during the last few decades, which has led to the paradigm of behavior based robotics, and more recently embodied artificial intelligence (Brooks, 1991; Pfeifer and Scheier, 1999; Iida et al., 2004). This approach deals with adaptive behavior in the context of decentralized control and physical system-environment interactions, and thus the body as a physical entity became a central issue of interest. In order to deal with complex dynamic environment with limited resources of sensors and actuators, adaptive behaviors cannot be reduced to control and computation only. The physical constraints of the system's own body and the environment have to be exploited. From this perspective, the concept of "cheap design" was formulated to systematically explore the relation between adaptive behaviors and morphological properties (Pfeifer and Scheier, 1999).

A number of researchers in biology and robotics have been attracted by the study of legged locomotion, because a legged robot in the real world continuously encounters new demanding situations derived from the physical constraints of their own body and the environment. We have been investigating the issues of legged robot locomotion by mainly focusing on the following two questions: how body dynamics can be used for behavioral diversity, and how body dynamics influences the sensory stimulation, and more generally cognitive processes.

In animals' locomotion a lot of control is not achieved by the brain alone, but through the interaction with the environment and the material properties of the limbs such as elasticity and damping (e.g. Dickinson et al., 2000). Based on these insights, roboticists have started building artificial creatures by exploiting similar principles for their designs (e.g. Collins, et al., 2001). In our investigations of one-, two- and four-legged robots (Figure 1), we found that legged locomotion can be achieved through extremely simple motor control by exploiting morphological properties and body dynamics (e.g. elasticity, rigidity, body weight distribution, and passive joints). An important discovery is that the exploitation of body dynamics can result in significant behavioral variations that are required for autonomous adaptive systems. It was shown that energy efficient self-stabilizing gait patterns can be generated by implementing passive elastic joints in the legged robots (Iida, et al., 2005; Iida et al., 2006).

(a) (b) (c) (d) (e)

Figure 1. Representative robotic platforms: (a) Stumpy, (b) Puppy, (c) BioLeg I, (d) J-Walker, and (e) Mini-Dog.

Body dynamics also significantly influences sensory stimulation and neural information processing. Through the interaction with the environment, i.e. through the robot's own dynamics, patterns of sensory stimulation are induced in different sensory channels. If these patterns originate from attractor states of the robot (e.g. from a particular gait pattern), the nature of these attractors will be reflected in the structure of the sensory information (Iida and Pfeifer, 2006). Thus, because these attractor states are the reflection of physically meaningful interactions (e.g. running forward at certain hopping height), by analyzing this sensory information, we as observers, but also the robot itself, can acquire a kind of basic type of symbol, i.e. discretely identifiable entities within a continuous sensory information space.

Although we are still in a nascent stage of our exploration, a further understanding of body dynamics will provide significant insights into adaptive behaviors of embodied systems. By implementing mechanisms for regulating body dynamics and more sophisticated sensory-motor coordination, we will be able to develop a set of interesting physical system-environment interactions on top of which a form of high-level cognition could be developed.

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