Morphological Computation: Connecting Brain, Body, and Environment

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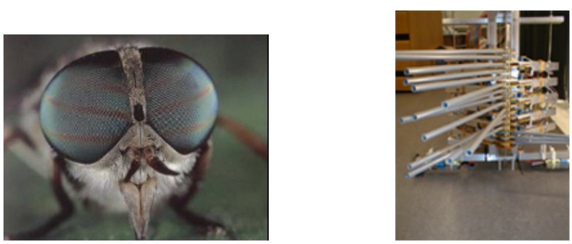
Traditionally, in robotics, artificial intelligence, and neuroscience, there has been a focus on the study of the control or the neural system itself. Recently there has been an increasing interest into the notion of embodiment not only in robotics and artificial intelligence, but also in the neurosciences, psychology, and philosophy. In this paper, we introduce the notion of morphological computation and demonstrate how it can be exploited on the one hand for designing intelligent, adaptive robotic systems, and on the other for understanding natural systems. While embodiment has often been used in its trivial meaning, i.e. "intelligence requires a body", the concept has deeper and more important implications, concerned with the relation between physical and information (neural, control) processes. Behavior is not the result of brain processes only, but there is a "task distribution" among brain processes (control), morphology, and materials. For example, the positioning of the sensors on the agent, the particular morphology (the anatomy), and the material properties of the muscle-tendon system (the biomechanical constraints) can be exploited for generating adaptive behavior. Morphological computation is about connecting brain, body, and environment (e.g. Pfeifer, et al., 2005, Pfeifer and Gomez, 2005, and Pfeifer and Bongard, 2005).

A number of case studies are presented to illustrate the concept: For sensor morphology, the Eyebot (Fig. 1), for body morphology and materials, the "Yokoi hand" (Fig. 2), and for exploitation of the interaction with the environment, the robot fish "Wanda" (Fig. 3). So, some of the processing is performed not by the brain, but



a. b.

Fig. 1. Morphological computation through sensor morphology - the Eyebot. The specific non-homogeneous arrangement of the facets compensates for motion parallax, thereby facilitating neural processing. (a) Insect eye. (b) picture of the Eyebot.

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by the morphology, by the materials, and the interaction with the environment. If we are to understand how behavior in natural systems comes about, and how we should design artificial systems, it is not sufficient to deal with control. In order to comprehend the function of the brain, we must not only look at the brain itself, but at how the brain is embedded in the physical organism, what the properties of this organism are, and what specific interactions the agent is engaged in. Similarly, in order to design good robots, one cannot only program the controller, but all the other aspects must be designed at the same time.

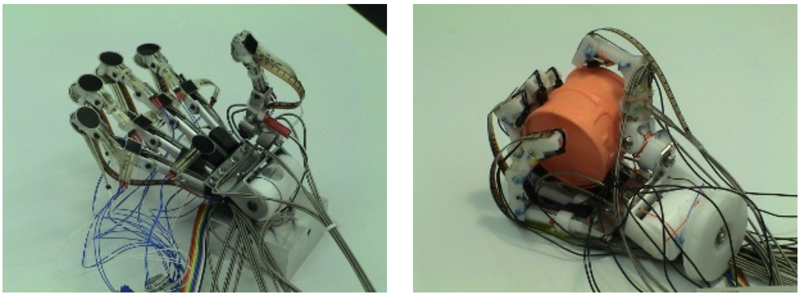

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Fig. 2. The "Yokoi hand". (a) The robot hand. (b) Grasping an object; through the particular shape of the hand, the deformable materials and the elastic tendons it self-adapts to a large variety of different bjects without a priori knowledge about their shapes.

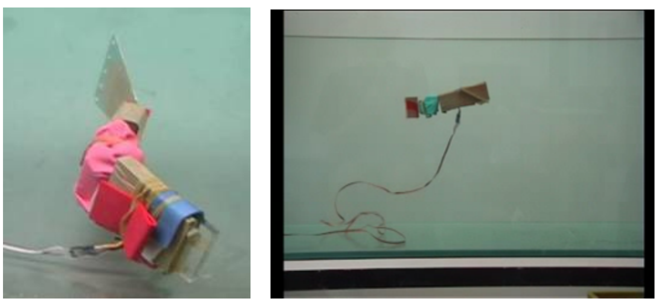

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Fig. 3. The robot fish W0anda". (a) View from above. (b) sideview while swimming. By exploiting the interaction with the environment, "Wanda" can reach any point in 3D space with just one degree of freedom of actuation (wiggling its tail fin).

References

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