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Morphology, control and passive dynamics

Traditionally, research in robotics has focused primarily on control. However, an increasing body of research supports the notion that the structure and mechanical characteristics of the robot body, that is its *morphology*, play a crucial role in behavior generation and control. The morphology not only determines the kinematics and dynamics of the robot, and thereby the possible repertoire of behaviors, but also affects the control required for these behaviors. A well designed morphology can lead to drastic reductions in control requirements, as well as improved controllability. On the other hand, a poorly designed morphology may lead to low controllability, require complex control algorithms, or in the worse case, simply be inadequate for the task.

The benefits of good morphological design have become apparent in robotics through the design of robots which utilize passive dynamics. Starting with the work of Tad McGeer who built self-stabilizing passive mechanisms which could walk down a slope in the absence of control, numerous robots have been developed by Steve Collins, Andy Ruina, Russ Tedrake, Richard van der Linde, Martijn Wisse and others demonstrating how well-designed morphologies can lead to reduction in control requirements and improved efficiency. The relevance of this idea extends beyond the design of passive dynamic walkers to the design of running robots (Marc Raibert, Hiroshi Kimura, Jorge Cham, Fumiya Iida, Tao Geng), climbing robots (Metin Sitti), underwater robots (Edward Colgate, Michael Epstein, Malcolm MacIver) and manipulators (Suguru Arimoto). The relationship between morphology and control requirements has been characterized by Rolf Pfeifer as the "morphology and control trade-off", making explicit the notion that an intrinsic relationship exists between morphology and control, and that control can be traded off for morphological properties. The discovery that the morphology can perform computation, also known as morphological computation (Chandana Paul), illuminates the main mechanism behind this trade-off. It shows that computational processes involved in control can be directly subsumed by the morphology, further corroborating the strong link between morphological design and control complexity.

In addition to the design of the morphology, the interaction between morphology and control also plays an important role in behavior generation. The origins of this idea can be traced back to the work of cyberneticists such as Ross Ashby and Grey Walter who demonstrated that behavior could emerge from the interaction of body and environment. Walter's turtles, for instance, despite having extremely simple controllers, displayed interesting behaviors due to their configuration and coupling to the real world. After a lull in the 1970s this idea was explicitly revived again in the 1980s in the context of embodied AI by Rodney Brooks. His behavior-based robots showed that the interaction of control, body and environment could lead to the emergence of intelligent behavior in various contexts, including hexapod locomotion, mobile robots and humanoids. The benefits of exploiting this interaction for behavior generation were also demonstrated, for example, in the work of Gentaro Taga in the context of biped walking, as well as the work of Max Lungarella and Luc Berthouze in the context of pendulating robots. In both instances, the global entrainment of the neural system, musculo-skeletal system and environment led to behavior generation which was stable and robust against perturbations. The notion of global dynamics introduced by Tomoyuki Yamamoto and Yasuo Kuniyoshi supports a similar point of view, by conceptualizing complex movements of a humanoid as the emergent outcome of well-timed but sparse interactions between morphology and control. In the fields of biology and biomechanics as well, studies indicating the beneficial effects of this interaction abound. Brown and Loeb, for example, introduced the notion of "preflex" referring to zero-delay stabilizing properties of active muscles which entirely bypass neural control. Studies conducted by Robert Full and his colleagues show that such self-stabilization in the mechanical system can assist in making the control of locomotion simpler and more robust.

Despite such ample evidence that morphology plays an extremely important role, the design of robot morphology still remains in the realm of heuristics. There are few theoretical methods which serve to analyze the role of morphology in control, or support the mechanical design of robots for improved controllability. This fundamental gap has led to the launch of a new research effort in this area. The first workshop explicitly addressing this issue was organized by Chandana Paul, Andy Ruina, Max Lungarella, Manoj Srinivasan, and Fumiya Iida in the context of the 18th International Conference on Intelligent Robots and Systems 2005 (Edmonton, Canada). This was a successful event which generated a lot of interest in the topic and solicited a number of high quality submissions. Following this, due to the growing interest in this emerging

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area, it was deemed that a more extended development of these ideas was necessary, and thus the Special Issue on Morphology, Control and Passive Dynamics was planned. An open call for papers was announced, which yielded high quality and original contributions.

As this Special Issue has the purpose of laying the foundations of a new research area, the selection of the papers placed great emphasis on originality and potential for future development. Some of the ideas presented here are still in their nascent stages, but they were selected as they present novel perspectives on the analysis of the interaction between morphology, dynamics and control. The papers of Paul, Iida et al. and Ishiguro et al. provide conceptual advances in understanding the interaction between morphology, control and behavior. The paper of Feliu et al. presents a novel technique for enhancing controllability using morphological design. The papers of Paluska et al., Matsushita et al. and Fend et al. present analytical methods and computational tools for investigating the effect of morphological characteristics on dynamics and behavior. Finally, the papers of Terada et al. and Rosenstein et al. introduce new control methods for better exploiting the dynamics of a given morphology for control. We hope that this collection of papers will yield new insights for the design of robots, and provide the basis for future theoretical developments in the area.

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