Biomechatronics for Embodied Intelligence of an Insectoid Robot

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Abstract. In this paper, the design and development of the new hexapod robot HECTOR is described. To benefit from bio-inspired control approaches for walking, it is fundamental to identify the most important morphological and biomechanical aspects and to associate them with biological control approaches whose function principles rely on those special body features. In a second step, these pairs can be transferred to the robot to lay the foundation for embodied intelligence. According to this idea, the main characteristics of HECTOR as presented here are the muscle-like elasticity in the self-contained joint drives with integrated sensor processing capabilities, actuated 2D body segment drives, the layout and orientations of the legs and joint-axes and a lean bus system for onboard communication.

Keywords: hexapod robot, six-legged walking, compliant joint, elastic actuation.

1 Introduction

The multiplicity of behaviours which are demonstrated even by putatively simple animals and the associated ability to adapt to different environmental situations are still superior to those found in technical systems like robots. Given this starting point, the design of bio-inspired robots seems to be a well suited strategy to approach the abilities of biological systems. However, at the beginning of a design process, the question which inspiration should be taken from the biological example and transferred to the technical system and which inspiration should be left out – perhaps for the sake of suitable simplification – is most important. In this work we report on such a process which resulted in the design of a novel bio-inspired hexapod robot named HECTOR (**HE**xapod **C**ognitive au**T**onomously **O**perating **R**obot). The robot follows the example of the stick insect *Carausius morosus* by utilizing important aspects of the morphology, biomechanics and neurobiological control.

With respect to biomechanics, current research in bio-inspired walking robots aims at improvements of leg constructions as it can be seen for instance in LAURON [15], modularisation of drive technology for limb joints as in the SPACECLIMBER [1] and also improvement of attachment organs like in the STICKYBOT [11]. Investigations of vertical movements led to the optimisation

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of leg geometry and control for climbing robots as shown e.g. in RISE [18]. An important feature in biological systems is intrinsic compliance in the actuation system and in parts also in the limb structure. An extreme example of the latter is the setup of elastic limbs e.g. in octopus which currently also finds its way into robotics [6]. HECTOR integrates some of the above mentioned inspirations like modular, elastic joint drives, additional body segment drives and the adoption of the leg geometry of stick insects.

With respect to control of walking robots, early successful implementations of coordinated walking behaviour was based on the subsumption architecture as proposed by Brooks [4] and implemented in the robot GENGHIS [5]. This architecture divides control hierarchically into several layers in which the lower layers have a reflex-like character and can be subsumed by higher layers. An early distributed neural network approach which takes into account that individual legs have their own rhythmic behaviour and are weakly coupled to neighbouring legs was embedded in ROBOT I by Beer and colleagues [3]. The principle idea that individual legs operate as autonomous agents which generate cyclic changes between swing and stance phase during walking mainly triggered by proprioceptive sensory inputs is also the foundation for the WALKNET controller [8,16]. HECTOR will use the WALKNET controller as a foundation to raise bio-inspired, reactive walking to a cognitive level while at the same time introducing and investigating sensor-actor loops for the sake of more stable gait generation in challenging walking situations. To support these sensor-actor loops, a novel, lean bus system (BioFlex Bus) for communication with those robot components related to walking has been developed.

For the current robot design we decided in favour of a hexapedal rather than for instance a bipedal setup because in two-legged walking much attention has to be paid to secure dynamical stability of the robot already during walking on flat terrain. The resulting careful operation impedes the exploration of an otherwise large parameter space. In contrast, static stability in a six-legged machine can be guaranteed in most situations. The number of DoF (Degrees of Freedom) is large enough to allow redundant postural solutions in different movement situations. Section 2 describes the transfer of morphological features to the robot, Sect. 3 introduces the implementation of bio-compliance in the construction of the self-contained, elastic joint drives and describes a concept for body segment actuation to increase manoeuvrability. Section 4 contains a description of a lean bus system for communication between on-board computer and all drive- and sensor-components. The paper finishes with a discussion and an outlook in Sect. 5.

2 Biomechatronic Transfer of Morphological Features

Besides bio-inspired control concepts for the coordination of legs and leg joints during walking [16], the transfer of important morphological features is a prerequisite for the analysis of the concerted interplay between function/control on the one side and shape/morphology on the other. HECTOR is modeled on the