Biologically Inspired Locomotion in Humanoid Robots

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In this article, we present a biologically inspired behavior-based locomotion approach for humanoid robots. On the low level, locomotion is realised by a combination of rythmic pattern generators to produce walking motions and postural reflexes which keep the robot stable and balanced. A higher level behavior could achieve goal-directed movements by exerting influence on the low-level behaviors. The approach was tested on a small humanoid robot which is based on the Kondo KHR-1 construction set.

1 Introduction

In the first section, we would like to give an understanding of the biological inspiration in our reactive locomotion control approach. The following two sections contain the technical specification of the robot with special attention paid to the electronic system and the software implementation of the control concept. Finally, we will present an experiment which shows the functionality of the overall architecture and discuss our conclusions.

2 Biological Inspiration

Our architecture is based on two approaches to robust and flexible real-world locomotion in biological systems which seem to be contradictory at first sight. These are the Central Pattern Generator (CPG) model and the pure reflex-driven approach. A CPG is able to produce a rhythmic motor pattern even in the complete absence of sensory feedback. The general model of a CPG has been identified in nearly every species even though the concrete instantiations vary among the species in order to reflect the individual kinematical characteristics in the animals.

The idea therefore seems to be very promising as a concept to realize locomotion in kinematically complex robotic systems, see Fig. 1, as it resembles the divide and conquer strategies that are reflected in nearly all solutions to complex control problems. Another model for the support of robust locomotion is also provided by evolution in the animal kingdom. This is the concept of reflex-based control [6]. A reflex can be viewed as a closed-loop control system with fixed input/output characteristics. In some animals, like the locust, this concept is said to actually perform all of the locomotion control and no further levels of control, like the CPG, are involved [5]. Whether or not complex motion control can be achieved only via reflex systems is subject to further discussion, however, the concept of a set of fixed wired reactions to sensory stimuli is of high interest to roboticists who aim at gaining stability in the system's locomotion. The design of the control architecture described here was thus driven by these two concepts. The CPG approach appeared to be interesting to generate rhythmic walking patterns which can be implemented computationally efficient, while the reflex-driven approach seemed to provide a simple way to stabilize these walking patterns by providing 1) a set of fixed situation-reactions rules to external disturbances, and 2) as a way to influence leg coordination among multiple independent legs [5]. Fig. 1 outlines the general idea.

This approach features the idea of continuous rhythmic locomotion as well as postural activity which is generated by spinal central pattern generators in vertebrate systems [9, 10]. For our technical implementation, these activities are solely defined by 3 parameters: amplitude, frequency, and offset of the rhythmic movement. Please note the possibility to set amplitude and frequency to zero by just modifying the offset parameter, which would result in linear, directly controlled joint movements. In those cases where amplitude and frequency have non-zero values, the activation patterns will result in a rhythmic movement of the joint around the offset (or baseline) with given frequency and amplitude. To produce complex locomotion patterns, like forward, left, right, or backward movements, all joints of the robot have to be activated simultaneously, while some (legs, shoulder, and hip) actually produce rhythmic activities, others, (like neck, elbow, etc.) will have their amplitude and frequency values set to zero maintaining a position at the offset value. One important aspect of central pattern generators is their nature as feedback control loops. The so-called proprioceptive information (current at a joint, angular displacement, and the difference between the desired angle and the actual joint angle) coming from the joints that are currently producing rhythmic activity is fed back into the controller and modify its activity.

3 The Hardware

The robot we used for our experiments is a modified version of the servo-based Kondo KHR-1 construction kit. It has 18 DOFs, 5 per leg, 3 per arm, and 2 as pan tilt unit for the head. The system is 40 cm high (30 cm shoulder-height) and has a total weight of 1.5 kg. Its mechanics are mainly part of the Kondo KHR-1 construction kit. As control unit we use a custom-made control-board which is composed of an MPC 565 PowerPC microcontroller mounted on a custom-designed mainboard. The MPC 565 is running at 40 MHz, has 2 MB flash memory and 8 MB RAM. Among others, it is equipped with three time processing units (TPUs) each with 16 channels, two analog digital converter modules

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