Adaptive Frequency Oscillators Applied to Dynamic Walking
II. Adapting to Resonant Body Dynamics

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Introduction

One of the important problems of robots with body dynamics is the fact that control methodologies are largely missing. While it is clear that body dynamics offers advantages such as energy efficient operation, simple control, and self-stabilization, we do not know how to systematically construct controllers that make use of those properties. Hitherto, finding the body modalities relies heavily on heuristics. The body dynamics is very dependent of the physical properties of the robot and the environment. Since these properties might vary over time, we need adaptive controllers that can find and track the body properties that are important for dynamic locomotion. In this contribution we show how adaptive frequency oscillators (AFOs) can be used to devise adaptive controllers that find –and readapt to– the resonant frequency of a quadruped robot and therefore elicit interesting locomotion behavior.

Adaptive Frequency Oscillators

Adaptive frequency oscillators are oscillators which are extended with an evolution law for the intrinsic frequency (or another parameter which influences the intrinsic frequency):

$$\dot{\omega} \sim xF(t)$$

where x is a state variable of the oscillator and $F(t)$ the input signal to the oscillator (for details see [4]). This adaptation law allows the oscillator to adapt its own frequency to one of the frequencies present in the signal. This adaptation is not mere synchronization, the initial frequency of the oscillator can be very far away from the frequency in the input signal.
The adaptive frequency Hopf oscillator has been introduced in [2] as an adaptive controller for a crawling robotic toy-system with body dynamics. In a subsequent contribution the adaptive frequency concept has been generalized for a wide class of oscillators and for the adaptive frequency Hopf oscillator it has been proved that such an oscillator adapts to one of the components of the frequency spectrum of the input [4].

Application to dynamic walking: Finding resonance in a quadruped robot

Certainly one of the most pronounced characteristics that a body can have in terms of passive dynamics are resonant or natural frequencies. Exciting such a body at the resonant frequency means that even with small inputs we can initiate movements of the body. Resonant frequencies are thus the primary candidate solutions for efficient locomotion exploiting body dynamics.
Adaptive frequency oscillators can be used in feedback loop with a plant (i.e. the robot) to find resonant frequencies of the plant [2]. Due to the dynamic formulation of the adaptation law the controller continously tracks changes in the resonant frequency (e.g. by change of weight).
We show how to devise an adaptive controller for legged robots with springs in their legs. We show results of the controller performance in simulations (cf. [3]) and the experimental robot PUPPY II (cf. [1]). Especially we will show how the controller successfully finds the resonant frequency, initiates locomotion, and how it re-adapts to changed body weight. We have shown that the convergence behavior of AFOs with a feedback loop can successfully be treated and understood with a linear plant[1], which constitutes a first and important step towards a *methodology for designing* adaptive controllers for robots with body dynamics.
As presented in another contribution to this workshop [5], the AFOs can be used to encode given dynamics into a CPG and modify the encoded limit cycle by sensory feedback to achieve stability for biped locomotion. AFOs make it thus possible to merge these two approaches for even more powerful development techniques for controllers for legged robots with passive dynamics.
The controller is extremely simple, no complicated signal processing techniques and no algorithmic processing are needed. Learning and control are embedded in the same dynamical system. No offline learning, no discrete learning trials are needed, and no exploration and exploitation phases needs to be distinguished. The formulation of controllers in the language of dynamical systems offers several advantages: robustness of the solutions (due to structural stability), the ease of fuse in sensor input, the possibility of fusing controller hierarchies, smooth transitions under parameter variations, to name a few.

References

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