Attractor-based postural control for a quadruped robot

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Introduction

Postural stability, body balance and orientation are fundamental factors that condition the success of locomotion in complex natural environments, a requirement if one wants to achieve autonomous robotic legged locomotion. This poses serious control problems in legged robots, requiring the coordination of a large number of degrees of freedom. This point is further exacerbated when one wants to devise a general solution for legged locomotion in more complex environments.

Analysis of different species has shown that there are individual central systems for posture and locomotion that interact when required [1]. However, it has been difficult to methodologically study the closed-loop postural system because it needs the integrity of the brainstem and spinal networks, as well the presence of sensory feedback for its normal function [2].

It is commonly accepted that locomotion in vertebrate animals origins from the spinal cord, where the Central Pattern Generators (CPGs) generate sustained rhythmic activations of muscle synergies that result in locomotor movements [3]. CPGs besides receiving commands from higher centers are also strongly influenced by closely interacting sensory information, the basis of locomotor adaptation. Sensory efferents from muscle spindles, Golgi tendon organs and cutaneous regions adapt and change the basic locomotor motions, while descending commands further adapt the locomotion based on more complex sensory information [1, 2].

Postural tasks are achieved by adapting and correcting the locomotor movements; of innate reflexes ready to be elicited depending on context; and sensory dependent responses that maintain the proper expression of locomotion in specific conditions. The postural reflexes and responses perform concurrent processing of (sometimes redundant) information from multiple senses, generating possibly competing and coordinating actions.

Standing postural control

In this work we start by addressing postural control in quiet standing, considering it a precursor for the design of a postural controller for locomotion. The postural controller is embedded in a CPG design based on coupled nonlinear oscillators proposed previously [4].

We hypothesize that the resulting limb corrective action is the overall output of parallel responses related to sensory information. It assumes that the integration of the parallel responses produce the final correct posture, acting as the integration of somatosensory signals. Postural responses work concurrently through a kind of competitive coordination, taking as input somewhat redundant sensory information and competing to act through legs’ actuators. Each response may be directly influenced by sensory information or based on a processed regulated variable (e.g. Center of Gravity).

Some of responses have been designed based on existing reflexes observable in animals (e.g. tilt compensation) and others in requirements from a robotic point of view. Further, some responses are coordinated among the four legs, allowing joined efforts when corrective movements of full amplitude from one leg are required.

CPG integration A network of four coordinated CPGs is responsible for generating the basic locomotor motions for each leg joint (for further details see [4]), with a set of parameters specifying the amplitude, frequency and offset of the rhythmic motion. In order to uniquely address the standing postural problem we turn-off the rhythmic activity, studying only the effects of the postural system and forgetting the rhythmic motions of locomotion. The postural system participates in the trajectory generation for each leg joints, hip swing, hip flap and knee.

Responses are designed as differential equations, and their integration is simply the sum of their dynamics (for full details see [5]). Table 1 summarizes the postural responses and its influencing sensory information.

Roll and pitch balance Sensors in the robot measure its roll and pitch angles, and the response extends or flexes each leg accordingly. Changing the height on each leg the
response changes the inclination of the body, opposing to changes in terrain slope so that the roll and pitch angles are reduced to a minimum (fig. 1).

**Center of Gravity adjustment** This response moves the robot’s CoG over to the center of the support polygon, increasing stability of the actual robot posture. Using information about its posture the robot knows where the CoG lies and where the center of the support polygon is located (fig. 2).

**Load distribution** This response distributes the weight of the body equally over the four legs. We estimate load information from joints by reading the PWM values. Legs which are above the load average should flex and the others extend.

**Touch control** When the robot’s feet lose ground contact, the robot loses support on that point. This response monitors the touch sensors in the foot and when it detects the lose of support, it searches for ground by extending the leg.

Sometimes the ground is too far and a fully stretched leg is still not able of regaining support. In this situation the response between the legs must be coordinated. The other legs should flex, lowering the body and allowing the leg with support lose to touch the ground.

**Leg disperser** We have verified that in certain conditions the fore and hind knees would collide, which caused a few stability problems. In order to avoid this undesired situation we designed a leg disperser which avoids the contralateral legs from touching.

**Posture reset** After a certain number of corrective movements the robot may lose its own initial posture. To force the quadruped to return to its initial position we implemented a weak attractor. The idea is to be weak enough so it does not disturb the other responses, but if allowed, it will slowly and surely return to the initial posture.

**Experiments**

The approach is applied to an AIBO ERS-7 quadruped robot to demonstrate the system’s feasibility. The robot stands over two independent moveable planes, subjecting the robot to change in inclination or a lose of foothold. The platforms rotates in opposite directions: $10^\circ$ for fore legs and $-5^\circ$ for hind legs (fig. 3).

The moving platforms will make the robot lose support on left fore and right hind legs, toppling the robot over its head. Postural responses counter-act these effects by extending the unsupported legs; shifting the CoG and maintaining the a stable body inclination. The different responses are shown for fore left leg (fig. 4).

![Figure 3: Snapshots of simulation. The robot maintains balance while two platforms move.](image)
Results

This approach to postural, or equilibrium maintenance, works well for quiet standing context. The parallel responses act based on different sensory modalities are general enough that the robot maintains its equilibrium even when faced with different postural tasks. Because we do not specify the final solution, we just design postural responses based on sensory information, the final posture is emergent from the interaction with the environment due to the integration of the different responses.

We expect to further explore these postural responses for the walking context. We assume that certain mechanisms which perform determined actions can be used to achieve different behaviors and can be elicited due to different intentions. e.g. the mechanism used to produce the crouched posture in the cat is also used to upslope or backward walking, and for to stalking a prey [6]. Responses used in the standing context 1) may possibly be used straight in the walking context; 2) could need some tuning depending on context; or 3) would be activated depending on behavioral context. For instance, preliminary experiments show that roll compensation can be used in the walking context with minimal adjustments (fig. 5).

In the future we will take in consideration automatic tuning and learning of activation and modulation of the responses according to behavioral and sensory contexts.

References


