Bio-inspired Control Framework for Legged Locomotion

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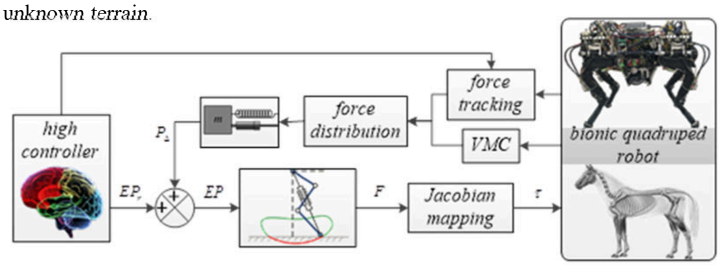
ABSTRACT

When traversing over the unknown terrain, both abilities of compliant locomotion and precise movements are crucial but remain an enormous challenge for quadruped prototypes[1]. Inspired by the **Equilibrium Point Hypothesis** in biology[2], this paper presents a simple and generic **Bio-inspired Cartesian Compliance framework** for quadruped robot. To begin with, the reference EP trajectories generated by high controller via impedance characteristic of the spring-like legs in operation space. Meanwhile, for complying with geometric uncertainty in the environment without sacrifice the balance performance, a uniform virtual model control scheme that simultaneously consider the force tracking and attitude regulation, is proposed. In addition, we propose an novel force distribution algorithm that modifies the reference EP trajectories online using admittance control model.

CONTROL FRAMEWORK

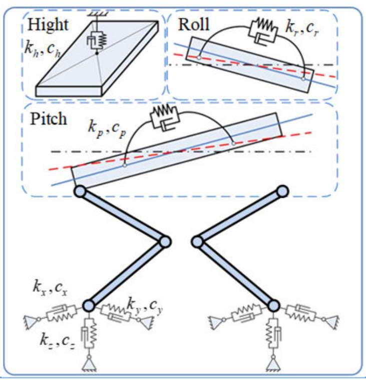
The main goal of this study is to explore a universal bio-inspired control framework for quadruped locomotion in very complex and difficult terrains. For this purpose, we proposed a foot-end compliance controller based on the mechanism of biological movement for 3D dynamic trot gait to traverse over the unknown terrain.



As we can see the proposed bio-inspired control framework, in consistent with the CNS, the high controller generates the reference EP trajectory. Then the requisite force in operation space is obtained via spring-damper model, which is similar with muscle behavior. Meanwhile, tactile sensory feedback for handling large distribution brings us more inspiration. The reference EP trajectory is on-line modified for simultaneously tracking the desired position and force during dynamic locomotion. In other words, a stability goal for maintaining trunk posture can be achieved using the virtual model control to generate desired force deviation. Then the difference between the actual force acquired by sensor and the specified force by the high controller, as well as the force deviation can modify reference EP trajectory by the admittance controller, avoiding the complex "inverse dynamic" problem of computing the torques at the joints.

APPROACH

Limb impedance and whole-body virtual impedance controller in the Cartesian space.



The relationship of whole-body impedance parameters and limb impedance parameters

$$k_p = \sum_{i=1}^{4} (f_i k_{iz} (P_{ix} - C_x)^2)$$

$$k_r = \sum_{i=1}^{4} (f_i k_{iz} (P_{iy} - C_y)^2)$$

$$k_h = \sum_{i=1}^{4} (f_i k_{iz})$$

Whole-body Force/Torque (H_W)

Pose Regulation

$$H_V = \begin{cases} M_V = -k_M\left(\theta_d - \theta'\right) - c_M \dot{\theta}' \\ F_V = -k_F\left(C_d - C'\right) - c_F \dot{C}' \end{cases}$$

Force Tracking

$$H_T = \begin{cases} M_T = \sum_{i=1}^{4} (F_i' - F_{id})(P_i - C) \\ F_T = \sum_{i=1}^{4} F_i' - F_{id} \end{cases}$$

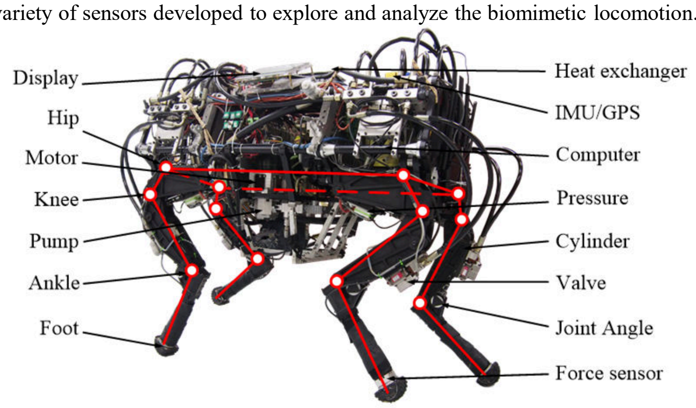
Force Disturbance

$$\Delta z_i = \Delta h - x_i \sin \Delta p + y_i \sin \Delta r \qquad \frac{F_{xi}}{F_{zi}} = \frac{F_{Wx}}{F_{Wz}} = \eta$$

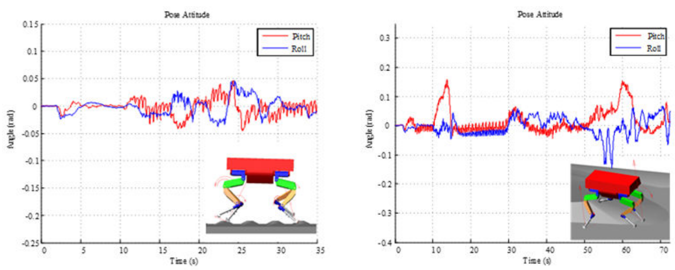
$$Bx = \begin{bmatrix} flag_1 & flag_3 & flag_4 & flag_5 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & b_{25} & b_{26} & b_{27} \\ b_{31} & b_{32} & b_{33} & b_{34} & b_{35} & b_{36} & b_{37} \\ 0 & 0 & 0 & 0 & b_{45} & b_{46} & b_{47} \\ b_{51} & b_{52} & b_{53} & b_{54} & b_{55} & b_{56} & b_{57} \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & -1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} {}^{C}f_{1y} \\ {}^{C}f_{3y} \\ {}^{C}f_{4y} \\ {}^{C}f_{6y} \\ \Delta p \\ \Delta r \\ \Delta h \end{bmatrix} = \begin{bmatrix} F_{Wy} \\ F_{Wz} \\ M_{Wx} \\ M_{Wy} \\ M_{Wz} \\ 0 \\ 0 \end{bmatrix}$$

RESULT

This is a latest version of the quadruped robot system described in [3]. It has a variety of sensors developed to explore and analyze the biomimetic locomotion.



Twe types of terrains for verifying the effective of the proposed controller.



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[1] M. Focchi, et al., "Torque-control based compliant actuation of a quadruped robot," IEEE International Workshop on Advanced Motion Control, 2012.

[2] Bizzi E, et al., "Does the nervous system use equilibrium-point control to guide single and multiple joint movements?" Behavioral and Brain Sciences, 1992.

[3] Mantian Li, et al., "Control of a Quadruped Robot with Bionic Springy Legs in Trotting Gait," Journal of Bionic Engineering, 2014.