ON THE HEXAPOD ROBOT'S GAIT OPTIMIZATION: A DYNAMIC PERSPECTIVE ON THE LIMBS ACTUATION

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1. INTRODUCTION

It is known that in hexapod robots, the feet's trajectory is the key feature for generating efficient gait. The kinematic parameters of the feet's motion, such as the bodies' velocity when reaching the trajectory's posterior extreme position, can significantly affect the interaction between the foot and the ground, and consequently, the limb's actuation. In the literature, common strategies to improve feet motion involve adjusting gait patterns and velocity [1]. Yin et al. [2] studied the relation of the foot's trajectory with the dynamic motion of the robot. In this work the foot's swing motion of a hexapod is analyzed. In the sequel of this process, a foot trajectory to improve the energy consumption is proposed, which is based on the torque developed at the joints. In addition, an optimization strategy to study the stride length, for both regular and irregular terrains, is proposed. Using locomotion performance parameters, a cross-examination between the Cost of Transport (CoT), Froude number, and stability is discussed.

2. DESCRIPTION OF THE MODEL

Figure 1 shows the ATHENA robot developed at the University of Minho, which multibody model is composed of 25 rigid bodies that are interconnected by 24 kinematic joints. Each limb is constituted by four rigid bodies, named coxa, femur, tibia, and foot. The connection between these bodies is established by three revolute joints, named after Torso-Coxa (TC), Coxa-Trochanterofemur (CTr), and Femur-Tibia (FTi), and by one fixed joint between the tibia and the foot. Each foot is modeled as spherical surface. The normal force that is applied to the feet during a contact event is expressed as

$$f_{\mathrm{n}} = \begin{cases} K\delta^{n} c_{\mathrm{e}} & \text{if } \dot{\delta} \le -v_0 \\ K\delta^{n}\left(c_{\mathrm{e}} + \left(1-c_{\mathrm{e}}\right)\left(3r^2 - 2r^3\right)\right) & \text{if } -v_0 < \dot{\delta} < v_0 \\ K\delta^{n} & \text{if } \dot{\delta} \ge v_0 \end{cases} \tag{1}$$

where K is the contact stiffness, n is a nonlinear power exponent, c_{e} denotes the coefficient of restitution, r is a parameter that relates the bodies relative velocity with the tolerance penetration velocity v_0, and $\dot{\delta}$ is the relative velocity between the foot and the ground [3]. The friction forces are computed based on a modified Coulomb's friction law, which is given by

$$\mathbf{f}_{\mathrm{t}} = \mu_{\mathrm{k}} f_{\mathrm{n}} \tanh\left(k_{\mathrm{t}} v_{\mathrm{t}}\right) \mathrm{sgn}\left(\mathbf{v}_{\mathrm{t}}\right) \tag{2}$$

in which μ_{k} represents the kinetic coefficient of friction, f_{n} is the norm of the normal contact force, k_{t} denotes the slope for null velocity, and $\mathbf{v}_{\mathrm{t}}$ is the relative tangential velocity between the two surfaces in contact [3]. The equations of motion of the hexapod multibody system follow the formulation proposed by Nikravesh [4].

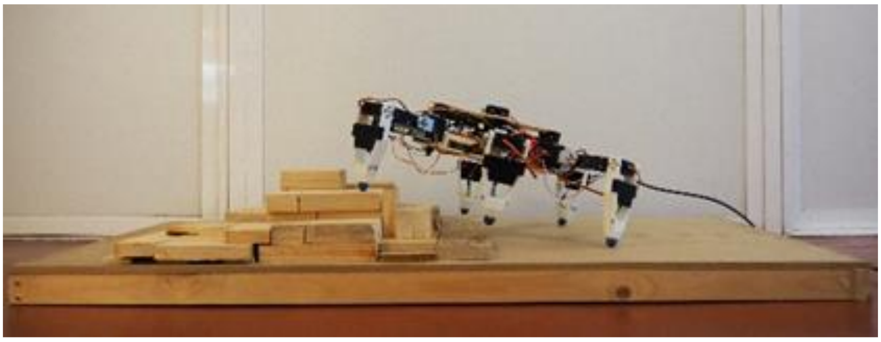


Figure 1. ATHENA hexapod robot.

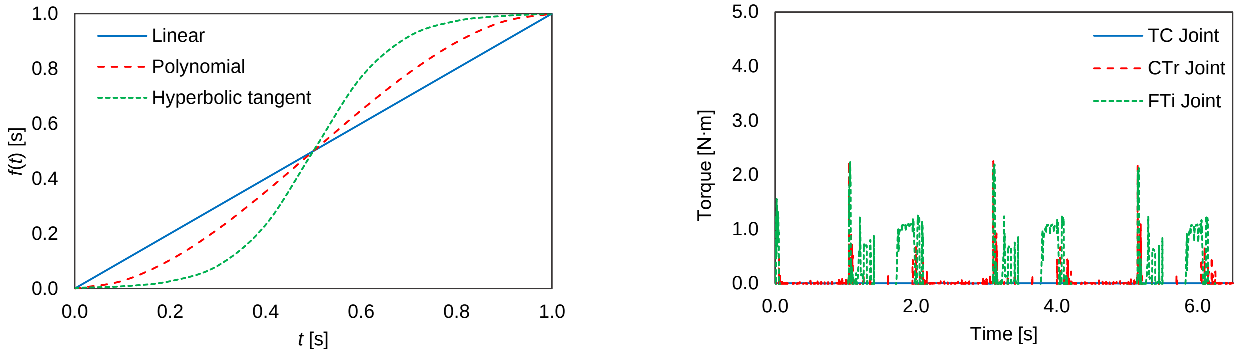
3. DESIGN OF ENHANCED LIMB ACTUATION

In order to assess the impact of the foot-ground interaction on the hexapod robot’s energetic consumption, the feet’s swing motion is examined. Given that the velocity of swing motion affects the forces involved in the foot-ground interaction, this work analyzes three different swing motion trajectories. In each trajectory, the feet’s position is generated by a cubic spline with identical control points, but the velocity is governed by a different function (linear, polynomial, and tangent). Therefore, the foot’s velocity during impact varies with the trajectory. Figure 2(a) shows the three trajectories under examination. Each swing motion was implemented in the hexapod robot’s equations of motion and a computational simulation of locomotion was performed. In the gait phase transition, the feet’s acceleration is lower in the polynomial trajectory. Subsequently, lower normal forces are applied to the feet during contact and the torque generated in each joint decreases, as is depicted in Fig. 2(b). Moreover, the cyclic acceleration provided by the polynomial trajectory improves the hexapod robot’s stability during contact events.

Considering that the step size also affects the locomotion efficiency in terms of energy consumption and stability. Thus, the most adequate stride length for regular and irregular terrain topologies must be assessed. Given the dimensions of the hexapod robot, the stride length must not exceed 0.21 m. Bearing that in mind, computational simulations, in which the stride length varies between 0.03 m and 0.21 m, are performed. For each simulation, the CoT, stability, and Froude number are assessed. It must be noticed that stability is measured by the variation of the torso’s angular velocities. With the computational simulation outcome, a model that relates these parameters with the stride length of the hexapod robot was defined. In order to obtain the stride length, an optimization strategy is formulated as

$$\begin{gathered}\min\left(n_{\mathrm{CoT}}(s),\, \delta\omega_{\mathrm{T}}(s),\ -n_{\mathrm{Fr}}(s)\right)\\ s\in\left[0.03,\, 0.21\right]\end{gathered} \tag{3}$$

in which n_{CoT} is the CoT, $\delta\omega_{\mathrm{T}}$ is the torso’s angular velocity, n_{Fr} represents the number of Froude, and s is the stride length. Considering the robot’s holonomic motion, the study was performed for longitudinal and lateral gaits.



(a) (b)

Figure 2. Trajectory analysis: (a) Schematic representation of the three analyzed trajectories; (b) limbs torque with a polynomial trajectory.

4. CONCLUDING REMARKS

This work studies the actuation of the hexapod robot ATHENA. The development of a multibody model to study the contact forces and moments applied to the hexapod robot during motion was presented. Computational simulations were conducted to obtain an optimal model for reducing the torque required by the kinematic joints, and subsequent decrease of energy consumption. Given the step size of the hexapod robot, the motion enhancement is further extended to the stride length, and an optimization methodology was proposed to improve the stability and energy consumption.

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