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Stance Phase Control System of a Jumping Robot

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Abstract: The paper treats the control of the jumping robot during the stance phase using the fractal model of the system. Considering an actuation system based on the Electro-Rheologic (ER) fluid controller, a fractal model is inferred. The linearized model and nonlinear models are studied and control frequential laws are proposed using YKP criterions. Observer models are proposed for linear and nonlinear systems and the global stability for "system-observer" is studied by Lyapunov techniques. Numerical simulations are presented.

Keywords**:** robotics, control, stability, observer, frequential criterion

1. INTRODUCTION

This paper analyses the control problem of a class of robots, the jumping biped robots, during the Stance Phase of a motion cycle. The motion study of these robots represented a fascinated attraction for a great number of researchers due to complexity control laws, the number of constraints and large possibilities to develop specific theories and technological achievements. A plethora of papers treats this topic and we wish to mention (Masalkino *et al*.,2018, Szolt *et al*.,2018) for their contribution at the implementation of the bipedal jumping and running motion strategies. The servo-technologies for the controllers that supervise the jumping functions are analysed in (Taima *et al*., 2009, Sang-Ho, 2009) The principles of the hoping motion by using the equivalence with the spring-loaded inverted pendulum model are studied in (Takenaka *et al*., 2009, Raibert, 1986). The dynamic analysis of the motion cycles and the identification of the control laws is presented in (Niiama *et al*., 2009).
Thisr paper treats the control of the jumping robot during the stance phase using the fractal model of the system. Considering an actuation system based on the Electro-Rheologic (ER) fluid controller, a fractal model is inferred. The linearized model and nonlinear models are studied and control laws are proposed. It should be noted that the literature (Dadras *et al*., 2017) propose solutions with control laws that are not practical implementable because they require the measurement of all fractal variables that are usually without a physical meaning. To avoid these problems, a class of control laws defined on the fractal model with respect to direct observable variables are proposed and frequential criterions are studied. A fractal observer model is proposed and the global stability "system-observer" is studied by Lyapunov techniques for approximate linear and nonlinear model. Numerical simulations are presented.
The paper is structured as follows: section 2 presents motion cycle of a jumping robot, section 3 treats the Stance Phase Model,, section 4 describes the fractal model, section 5 treats the control system and section 6 verifies the control techniques by numerical simulations.

2. JUMPING MOTION CYCLE

A bipedal motion cycle is shown in Fig 1. (Ivanescu *et all*., 2018) There are two main phases: Stance Phase when the foot is in direct contact with the ground and Flight Phase when the robot leaves the ground. The motion is determined by two legs, each leg having a mechanical architecture consisting by an elastic lower configuration and an upper configuration that ensures the actuation and damping effect (Fig 2). An ER driving system allows the ER viscosity modification and the implementation of the control strategies.

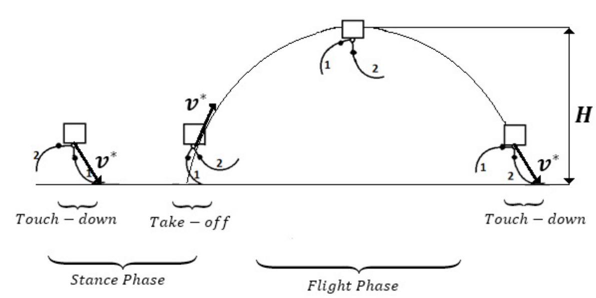

Fig.1. Motion cycle

3. STANCE PHASE MODEL

The mechanical architecture is presented in Fig 3. The system is a two-leg system where the upper component is a rigid beam and the lower component is an elastic curved structure. The geometrical parameters are shown in Fig 3. The massless legs are considered, all gravitational components are concentrated in the Centre of Gravity (COG). The dynamic model of the robot in the stance phase is obtained using Lagrange equations (Raibert, 1986).

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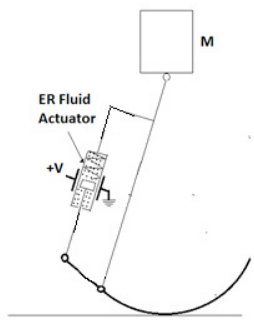

Fig. 2. Leg configuration

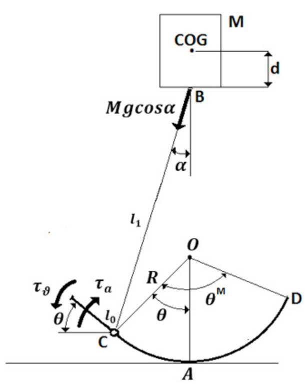

Fig. 3. Geometrical leg model

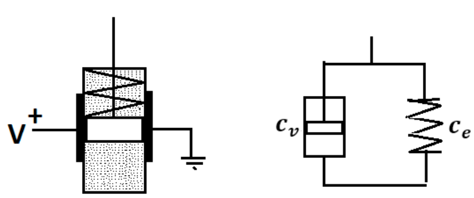

Fig. 4. ER fluid model

$$J\ddot{\theta}+\frac{\partial V_G}{\partial \theta}+\frac{\partial V_e}{\partial \theta}=\tau_a\text{-}\tau_\theta \tag{1}$$

where V_G, V_e are gravitational and elastic potential, respectively, J is the equivalent inertial moment, τ_a is the actuator torque and τ_θ represents the viscoelastic component,

$$V_G \approx Mg(d+l_1+R-R\cos\theta) \tag{2}$$

$$V_E=\frac{1}{2}\int_0^\theta \kappa_f(\theta)\,\theta^2\,d\theta+\frac{1}{2}\kappa_s l_0^2\theta^2 \tag{3}$$

The viscoelastic behaviour is determined by two components: a classical viscous friction in the rotational articulation C (Fig 3) defined by $c_{v0}\dot{\theta}$ and the viscoelastic component created in ER damper. This component is analysed by using the fractional Kevin-Voigt model in which a pure elastic phase defined by the elastic coefficient c_e is connected in parallel with a fractional viscoelastic phase that is characterized by coefficient c_v and fractional exponent β (Fig 4). The stress-strain relation is (Psaola *et all*., 2013)

$$\sigma(t)=c_e\xi(t)+c_v D^\beta\xi(t) \tag{4}$$

where $D^\beta\xi(t)$ is the Caputo fractional derivative of order β,

$$D^\beta\xi(t)=\left({}_t^c D_0^\beta\xi\right)(t) \tag{5}$$

In this analysis, the viscoelastic components are characterized by $0<\beta<1$ that correspond to an intermediate state between elastic and viscous fluid components. Substituting these components (2-5) in (1) and considering the following constraints $l_1 \gg R, \alpha \ll \theta$, after simple calculations, results

$$J\ddot{\theta}+c_{v0}\dot{\theta}+c_v D^\beta\theta+\kappa_e\theta+MgR\sin\theta=\tau_a \quad , \quad \theta\in\Theta \tag{6}$$

where Θ is determined by the admissible values of the geometrical configuration during the motion, and κ_e is the elastic equivalent coefficient, $\kappa_e=c_e+2EI+\kappa_s l_0^2$,(the variable t was omitted). The last term represents the nonlinear component determined by the gravitational forces. Assume that the viscoelastic exponent is β =1/2. The initial conditions are defined by the initial position and velocity,

$$\theta(0)=\theta_0,\ \dot{\theta}(0)=\dot{\theta}_0 \tag{7}$$

4. STATE MODEL

For the stability analysis and the identification of the oscillation regime, the following state variables are defined,

$$\theta(t)=\theta_1(t) \tag{8}$$

$$D^{\frac{1}{2}}\theta_1(t)=\theta_2(t) \tag{9}$$

$$D^{\frac{1}{2}}\theta_2(t)=\theta_3(t) \tag{10}$$

$$D^{\frac{1}{2}}\theta_3(t)=\theta_4(t) \tag{11}$$

Substituting (7-10) into (6), yields

$$D^{\frac{1}{2}}\theta_4(t)=-\kappa_e\theta_1(t)-c_v\theta_2(t)-c_{v0}\theta_3(t)-MgR\sin\theta_1(t)+\tau_a \tag{12}$$

This equation can be rewritten as,

$$D^{\frac{1}{2}}\boldsymbol{\theta}(t)=A\boldsymbol{\theta}(t)+g(\boldsymbol{\theta})+b\,\tau_a(t) \tag{13}$$

where $\boldsymbol{\theta}=[\theta_1\ \theta_2\ \theta_3\ \theta_4]^T$ is the fractal state vector of the dynamic model. The output is defined by the direct measurable variable

$$y(t)=\theta(t)=c^T\boldsymbol{\theta}(t) \tag{14}$$

The gravitational nonlinear term is $g(\theta)=[0\ 0\ 0\ MgR\sin\theta_1]^T$. This component verifies the inequality