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Investigating Balancing Control of a Standing Bipedal Robot With Point Foot Contact

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Abstract: Comparing with wheeled or tracked moving machines, legged robots have potential advantages, especially when considering moving on discontinuous or rough terrain. For many bipedal robots, balance in the standing position is easy to maintain by having sufficient contact area with the ground. For some bipedal robots, the Zero Moment Point (ZMP) control method has been successfully implemented in which the center of mass is aligned above the support area. However, the balancing issue while standing becomes challenging when the contact area is very small. This paper presents a controller which is developed to balance a bipedal robot with coupled legs which have point foot contact. It is necessary to investigate the non-linear characteristics of the system. A pole-placement control method is used, and noise issues with sensing higher motion derivatives are investigated. The simulation-based evaluation indicates limitations that need to be addressed before experimental implementation.

Keywords: center of mass (CoM), balance, bipedal robot, pole placement

1. INTRODUCTION

Considering moving on rough terrains, such as soft and uneven surfaces, legged robots have potential advantages comparing with wheeled or tracked vehicles (Hardarson, 1970). The isolated foot support area avoids the requirement for continuous ground. In the last few decades, bipedal robots have attracted researchers` attention. Several successful two-leg walking robots have been presented to show the motion mechanism principles, such as Asimo (Sakagami, 2002), ATLAS and PETMAN (Raibert, 2010). Considering the standing position, most of these platforms solve the balancing problem by having sufficient foot contact area with the ground. The Zero Moment Point control method has been successfully implemented to maintain balance by controlling the centre of mass above the support area while the robot is standing or slowly walking (Erbatur, 2002). An intermittent control strategy might be a solution to solve the body sway issue with a smaller foot contact (Bottaro, 2005). However, the problem is still very challenging when the support area is limited to point contact.

The Bath Bipedal Hopper (BBH) is a small size hydraulic actuated bipedal hopping robot, which is developed to design and test advanced controllers. The foot support area of the BBH is very small, and can be approximated by a point. One mode of operation is balancing while standing rather than hopping, and control for this mode is considered in this paper. A double inverted pendulum model is used to represent the BBH. A pole placement controller is developed and tested in simulation. Evaluation indicates the feasibility of this method and makes suggestions for further research.

2. HARDWARE OF THE BATH BIPEDAL HOPPER

As Fig. 1 shows, the basic design concept of the BBH comes from kangaroos, which are the largest animal using a bipedal hopping mechanism on the planet. The BBH has an upper body and two lower legs. The upper body consists of a main controller, which is an industrial PC (PC104 format), a manifold integrated with proportional valves and supporting framework. A hydraulic cylinder actuates the fore-aft hip rotation of both legs, i.e. this motion of the legs is coupled together. The two lower legs are hydraulic actuators with position sensors in parallel. There is an inertia measurement unit (IMU) attached to the upper body to measure the body rotation angel. An encoder is used to measure the angle at the hip point. Each foot consists of an aluminium alloy hemisphere covered in hard rubber. The BBH was designed to achieve locomotion using kangaroo-like hopping. Fig. 2 shows a simplified 3D model of BBH. Table 1 shows the list of some key components.

Table 1. Key components

Components	Model	No.	Notes
Valves	Moog E242	3	
Cylinder	Hoerbigger LB6 series	3	
Position sensor	Active sensor PLS0956 series	2	Measure the leg length
Encoder	Hengstler RI32	1	Measure the hip angel

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IMU	YEI-Lab IMU	1	Measure the body rotation
Controller PC	Terasoft Microbox 2000	1	PC104 mainboard

Fig. 1. Hardware of the Bath Bipedal Hopper

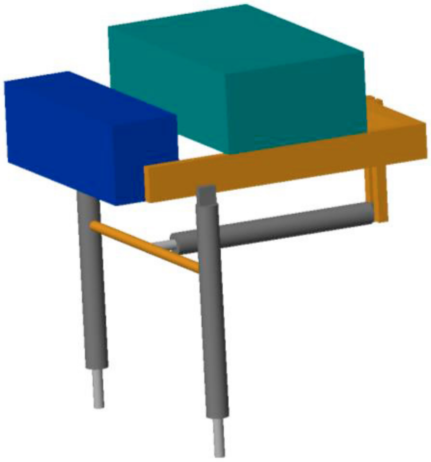

Fig. 2. Simplified 3D model of the BBH

3. MODELLING

3.1 Double inverted pendulum model

The inverted pendulum model has been successfully used to help design one-leg hopping robots (Kajita, 1989). A double inverted pendulum model is appropriate to analyse the motion of the BBH. As shown in Fig. 3, the model consists of two rigid bodies, an upper body and a lower body (representing the leg-pair), connected with revolute joint 1 (hip joint). The bottom of the lower body, i.e. the foot is connected to the ground using revolute joint 2 in the model. Using small angle approximations, we are trying to maintain the combined Centre of Mass (CoM) of the overall model vertically above revolute joint 2 by applying an active torque at revolute joint 1.

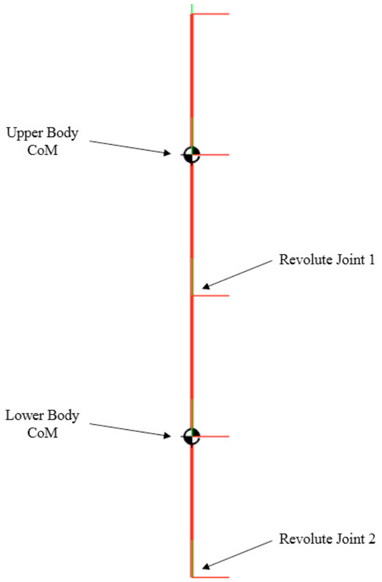

Fig. 3. Double inverted pendulum model

3.2 Dynamic analysis

The force analysis of the upper body is shown in Fig. 4.

Consider the force on upper body and taking moments about the revolute joint 1 gives (1), (2) and (3):

$$-F = M_u(l_u\ddot{\theta}_u + l_l\ddot{\theta}_l) \tag{1}$$

$$T_{act} - M_u g l_u \theta_u = J_u \ddot{\theta}_u \tag{2}$$

$$J_u = \frac{1}{3} M_u (2l_u)^2 \tag{3}$$

Where M_u is the mass of the upper body, l_u is the length from the upper body`s CoM to revolute joint 1, l_l is the length of the lower body, J_u is the moment of inertia of the upper body. Combine (1), (2) and (3) gives:

$$\frac{\theta_u}{T_{act}} = \frac{3}{4M_u l_u^2 s^2 + 3M_u g l_u} \tag{4}$$

Fig. 5 presents the force analysis of the lower body; taking moment about revolute joint 2 gives (5) and (6).

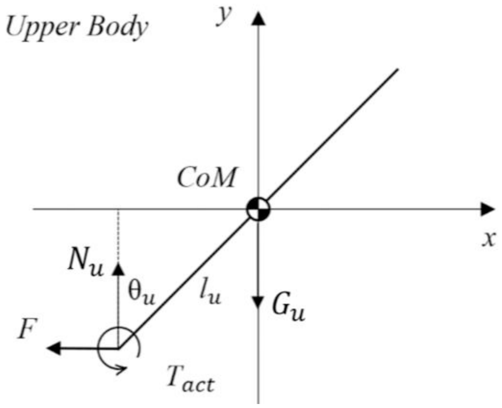

Fig. 4. Upper body force analysis