

GAIT PLANNING FOR ONE-LEGGED ARTICULATED HOPPING ROBOT

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ARTICLE DETAILS

ABSTRACT

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A gait planning procedure for planar one-legged articulated hopping robot is proposed in this paper. Its major advantage is the capability to design the take-off velocities of the mass center of the robot in X and Z axes, which is of quite importance for the schedule of hopping height and distance. To this end, a simplified robot model with a concentrated mass and a virtual telescopic leg connecting the hip and the toe of the robot is given first. With the application of cubic spline interpolation, the gaits of the robot on the ground and in the air are then both obtained from the inverse kinematics of the simplified robot model. Finally, the planned gaits of the robot are verified by the animation of a Matlab SimMechanics model of the hopping robot.

KEYWORDS

Hopping robot, gait planning, Matlab SimMechanics model

1 INTRODUCTION

Based on a study, the one-legged articulated hopping robot has attracted intensive attentions recently not only for its excellent mobility over uneven terrains and obstacles, but also for the fact that it is usually the prototype of more complicated multiple legged robot with point foot, to name but a few, the BigDog (a dynamically stable quadruped robot created in 2005 by Boston Dynamics Company, USA), the RABBIT (a biped robot located at the Automatic Control Laboratory of Grenoble (LAG), France), and ERNIE (a biped robot located at the Locomotion and Biomechanics Laboratory at the Department of Mechanical Engineering, The Ohio State University, USA) [1-8]. The major merits of these legged robots are their adaptability to the ground status and high energy utilization, which usually mean the high speed of locomotion in field environment. According to research, the point foot robots may have more challenges on stability control than the flat foot ones (e.g., Asimo, a biped robot of Honda Company, Japan) do due to the static instability from the shape of their feet [9]. In this regard, the gait planning and control study of articulated one-legged hopping robot could be viewed as the foundation of the counterparts of the multiple legged ones.

2. ROBOT MODELS

2.1 Planar One-Legged Articulated Hopping Robot

The planar one-legged articulated hopping robot discussed in this paper consists of three links as shown in Figure 1(a), i.e., the body (link 3), the thigh (link 2) and the crux (link 1), respectively. Links are connected by the hip and the knee joints rotating in the sagittal plane. External torques are applied to the joints. Applying the Lagrange equation of motion, the dynamic model of the one-legged articulated hopping robot is obtained as

$$\mathbf{M}\ddot{\mathbf{h}}(\theta) + \mathbf{G}(\theta) = \mathbf{T} \quad (1)$$

in which \mathbf{M} is the inertial matrix, \mathbf{h} is the Coriolis force vector and \mathbf{G} is the gravity force vector, and \mathbf{T} is the torque vector, respectively.

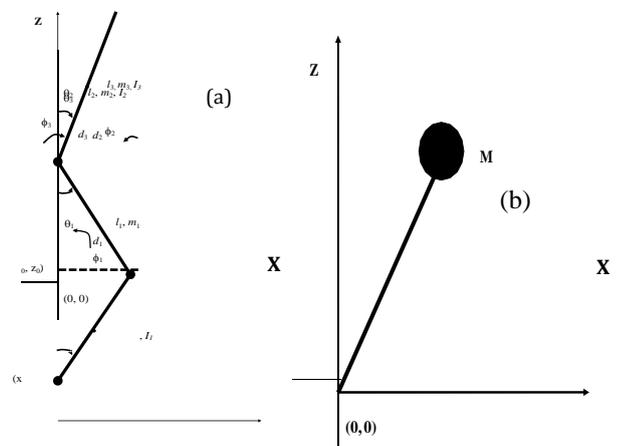


Figure 1: One-Legged Articulated Hopping Robot: (a) Stick Model; and (b) Simplified Model.

2.2 Simplified Robot Model

Due to the complexity of the articulated hopping robot, it is hard to plan the robot gaits directly with the model in Figure 1(a). Instead, a simplified model which consists of a concentrated mass and a virtual weightless telescopic leg connecting the hip and the toe of the robot is given in Figure 1(b) to make the gait planning procedure for the hopping robot. When the trajectories of the mass center and toe are determined, the inverse kinematics of the hopping robot based on the topology in Figure 1(a) is applied to get the corresponding joint angular quantities (distances, velocities and accelerations).

2. GAIT PLANNING

Before the gait planning, several assumptions are made, that is, (i) no slide exists between the ground and the toe of the hopping robot; (ii) the body of the robot keeps up-right during the whole Period of

hopping; (iii) the mass center of the robot is located directly above the hip of the robot with time-invariant distance.

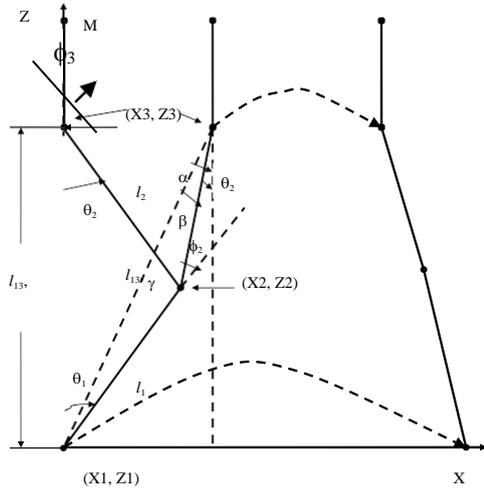


Figure 2: Planned Trajectories of Hip and Toe of One-Legged Articulated Hopping Robot

One period of hopping can be divided into two phases: the stance phase and the flight phase. At the beginning of the stance phase, the virtual leg of the robot is compressed to the shortest length. After that, it is released and the total mass is pushed forwards and upwards. When the velocities of the mass center in the directions of X and Z axes reach the pre-designed values, the robot takes off and enters the flight phase. The ballistic trajectories of both the mass center (directly above the hip) and the toe of the robot can uniquely determine the joint angular quantities by the plane geometry if the body keeps up-right. In this end, the trajectories in above two phases will be created subject to the following constraints:

(a) At initial time t_0

$$\begin{aligned} x_c(t_0) &= x_0; & x_f(t_0) &= x_0; \\ \dot{x}_c(t_0) &= v_{x1}; & \dot{x}_f(t_0) &= 0; \end{aligned} \quad (2)$$

$$\begin{aligned} z_c(t_0) &= l_1 \cos \theta_{10}; & z_f(t_0) &= z_0; \\ z_c(t_0) &= z_0; & z_f(t_0) &= z_0; \end{aligned} \quad (3)$$

(b) At take-off time t_1

$$\begin{aligned} x_c(t_1) &= x_1; & x_f(t_1) &= x_0; \end{aligned} \quad (4)$$

$$\begin{aligned} \dot{x}_c(t_1) &= v_{x2}; & \dot{x}_f(t_1) &= 0; \\ z_c(t_1) &= z_1; & z_f(t_1) &= z_0; \end{aligned} \quad (5)$$

$$\begin{aligned} z_c(t_1) &= v_{z1}; & z_f(t_1) &= v_z \\ \dot{z} & & & \end{aligned}$$

(c) At landing time t_2

$$\begin{aligned} x_c(t_2) &= x_1 + v_{x1}(t_2 - t_1); \\ x_f(t_2) &= x_c(t_2) + x_1; \end{aligned} \quad (6)$$

$$\begin{aligned} \dot{x}_c(t_2) &= v_{x2}; & \dot{x}_f(t_2) &= 0; \\ z_c(t_2) &= z_1; & z_f(t_2) &= z_0; \end{aligned} \quad (7)$$

$$\dot{z}_c(t_2) = v_{z1}; \quad \dot{z}_f(t_2) = v_{z2};$$

in which x_c , z_c , x_f and z_f are the coordinates of the mass center the mass center and the toe of the hopping robot, respectively;

θ_{10} and θ_{20} are the initial values of the joint angles θ_1 and θ_2 , respectively; v_1, v_2, v_3, v_x, v_z

$$v_1 \quad v_2 \quad v_3 \quad v_x \quad v_z$$

z_1, t_1 are the pre-designed quantities, respectively; and the landing time t_2 can be estimated with

$t_2 = \sqrt{2v_{z1} / g}$. The cubic spline interpolation is used for the trajectories implementation with the Matlab subroutine "spline.m". The inverse kinematics relationship is then obtained by the plane geometry as shown in Figure 2, as follows

$$\theta_2 = \arccos\left[\frac{l^2 + l_2^2 - l_3^2}{2l_1l_2}\right] \quad (8)$$

$$\theta_3 = \arcsin\left[\frac{x_1 - l_2 \sin \theta_2}{l_3}\right] \arccos\left[\frac{l_2 \sin \theta_2}{l_3}\right] \quad (9)$$

in which

$$\theta_1 = \arccos\left[\frac{l^2 + l_2^2 - l_3^2}{2l_1l_2}\right] \quad (10)$$

3. ANIMATION VERIFICATION OF GAIT PLANNING

3.1 Matlab SimMechanics Model for Hopping Robot

For the verification of the gait planning, a Matlab SimMechanics model of one-legged articulated hopping robot is built as shown in Figure 3 [10]. SimMechanics is the graphic multibody simulation tool for modeling three-dimensional mechanical systems in the Matlab Simulink environment.

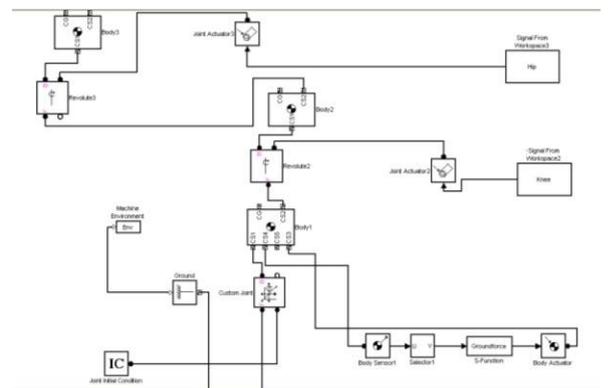


Figure 3: Matlab SimMechanics model of one-legged articulated hopping robot.

Therefore, the 3-D animation visualizing the hopping action of the robot can be executed for the verification. In Figure 3 it is observed that the model consists of 3 rigid bodies, 2 revolute and 1 custom joints representing the DOFs of the links respectively. The angular quantities of the hip (θ_1, θ_2 and θ_3) and the knee (θ_2, θ_2 and θ_2) are fed into the joint actuators to drive the robot jumping forwards and upwards with the velocity v_{x2} and v_{z1} .

3.2 Animation Verification

The parameters of the robot are given in Table 1. The take-off velocities in X and Z axes are both 1m/sec. Using Equations (2)-(10), the planned deflection angles of links ($t = 0 - 0.41$ second) are obtained as shown in Figure 4. By feeding the angular quantities to the joint actuators of the SimMechanics model, the hopping animation is presented in Figure 5. It is observed that the robot can successfully hop within one period (stance phase + flight phase).

Table 1: Parameters of The Hopping Robot

Link	Mass (kg)	Moment of Inertia (kg.m ²)	Length (m)	Location of Mass Center (m)
Body (3rd)	20	1.1 (I_3)	0.4 (l_3)	0.2 (d_3)
Thigh (2nd)	3.7	0.08 (I_2)	0.4 (l_2)	0.2 (d_2)
Crux (1st)	3.2	0.08 (I_1)	0.4 (l_1)	0.2 (d_1)

4. CONCLUSION

In this paper, the gait planning for planar one-legged articulated hopping robot is discussed and the hopping animation is executed by using the Matlab SimMechanics model. The research is in the initial stage currently and the future work probably includes (but is not limited to) (i) the optimal gait planning with the objective function or subject to the constraint

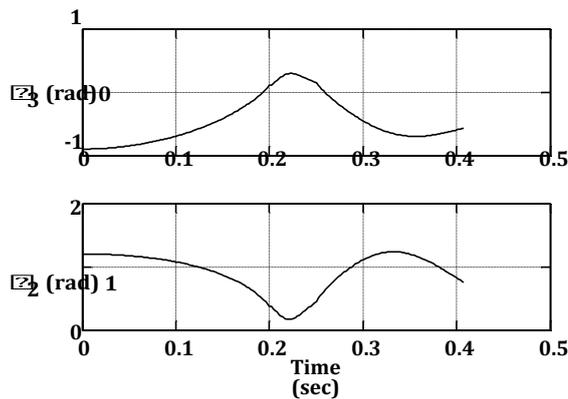


Figure 4: Planned deflection angles of links (see Figure 2 for notation).

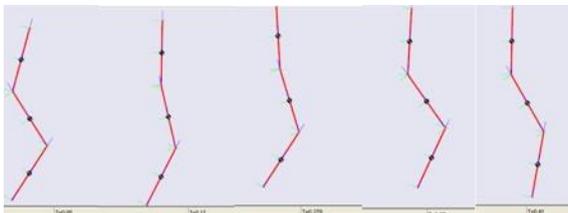


Figure 5: Hopping animation of Matlab SimMechanics model.

of energy saving, driving torques affordability, etc.; (ii) the asymptotic stability control of the hopping robot over the whole period; and (iii) the joints fault detection of the robot.

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