Investigation Of Multi Joint Jumping Robot Movement

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Abstract

Current research devoted to the question of development the mathematical model of the multi joints robot moving with a jump from a rough surface under the action of movement of joints from each other. The scheme of 4-joints jumping robot that equipped with controlled electromechanical actuator is represented in the current paper. The robot imitates the jump of a frog or a grasshopper. Mathematical model is developed which contains the description of a system which shows the regularities of motion of jumping technical and biological systems and also practical recommendations for a jump.

Keywords: mobile jumping robot, multi-link object, control system, jump from a surface.

1. Introduction

The interest to the robots which take-off while moving is great because they have cross-country power even where the road is rough. Thus helps to examine the territory after the earthquake or other emergency situation when the robot can only jump [1].

The structure and mechanism of multijoint jumping robot is the same as for the biologicals which move with the help of jumps: grasshoppers, frogs, kangaroos. The same mechanism is used by the sportsmen during long-jump.

Many scientists were interested in the questions of the way these devices move. Thus in [2] the ways of directional stabilization of robot which contains nonlinear source of energy are observed. In [3] the motion control system of pneuomelastic robot is examined. It allows change the jump length in a long range. The way of control of the jump height of a robot with resonant leg is described in [4] where the analysis of analytical decisions of robot movement for the time and energy optimal motion control is conducted. Also the results of the experiments are described which confirm the working capacity and effectiveness of the resonant leg.

Some of the research works describe the class of jumping robots as vibration robots which lift off the surface. The research of motion control of dual-mass system which consists of outer and inner parts which are correspondingly the body and balance weight on the firm rough surface which lift off is described in [5]. In this article the influence of angulator of balance weight rotation which acts as a control parameter of height and length of a jump. It also controls the pathway of the body. Besides there is the dependence between the robot motions and rotation of the balance weight. In [6] the results of the mathematic model of dual-mass jumping robot acting with different rotation speed of the balance weight is described. Also flight phases and robot's landing on the surface is examined. The mathematical model of jumping minirobot and differential equations which describe its motion during the flight phase and during its being on the area of bearing is described in [7]. At the same time the principles of robot’s motion are examined not enough which limit the use of such devices and do not let create high-performance robots moving with lift off.

2. The Description of a Robot

Jumping robot (see the figure 1) consists of units 1, 2, 3 and 4. Unit 1 periodically interacts with the area of bearing 5. Units 1 and 2, 3 and 4 are connected with each other by the rotary actuator 6 and 8 accordingly, units 2 and 3 by the sliding-stem actuator. Actuators 6 and 8 create the moments M12 and M34 which make units 2 and
4 rotate through an angle $\alpha_{12}$ and $\alpha_{34}$ about axes $H$ and $A_1$ and actuator 7 helps unit 4 to move about 3 under the action of force $F_{23}$.

Each jump of a robot has 3 phases: acceleration, flight and landing. In the first and third phases the robot interacts with the area of bearing, in the phase of flight the robot moves with the lift off the surface.

The jump of a robot looks the following way. The phase of acceleration begins when it ordinate of $A_1$ and $A_2$ of the part 4 are equal to zero, so that these points are on the surface 5, unit 2 of the leg is inside the body. In this phase actuators 6 and 8 rotate the robot and unit 2 through given angles $\alpha_{12}$ and $\alpha_{34}$. After that the body under the action of force $F_{23}$ created by the actuator 7 begins to move along unit 2 till unit 1 gets off the surface 5. Point $A_1$ of the body moves along the straight line HH1 and reaches point H1 at the beginning of the phase of flight and the length of the exposed leg 1 becomes equal to the value $L$. In the phase of flight unit 2 gets fully inside the body with the help of actuator 7 till the points $A_1$ and $H$ coincide and unit 1 rotates by the actuator 6 so that its support end coincide with the side $A_1A_2$ of the body. Robot begins the phase of landing when the point $A_1$ or $A_2$, $A_3$, $A_4$ of the body begins to interact with the area of bearing. Further the body rotates till the second point of the body touches the surface. The second point is accompanied by the normal reaction.

In the reference point $A_i$ in the phase of acceleration or landing there appears rubbing friction force described by the Coulomb’s law:

$$F_{pi} = \begin{cases} 
-fN_i \text{sgn}(\dot{X}_i), & \text{if } \dot{X}_i \neq 0; \\
F_i, & \text{if } \dot{X}_i = 0, |F_i| \leq fN_i; \\
fN_i \text{sgn}(F_0), & \text{if } \dot{X}_i = 0, |F_0| > fN_i,
\end{cases}$$

(1)

Where $F_0$ denotes resultant force, except rubbing friction force; $f$ is coefficient of sliding friction; $N_i$ is normal reaction in the control point; $\dot{X}_i$ - the speed of the point $A_i$ along the axis Ox. The force of viscous resistance acts on the side of the environment where the resultant vector is in the center of mass of the body and is defined by the equation 2.

$$R = \mu_r \dot{r}_c,$$

(2)

3. Mathematical Model of a Robot

Let us introduce 2 coordinates systems: absolutely fixed Oxy and relative system $Cx_1y_1$ which is connected with the body of robot so that the beginning of the coordinate $C$ coincides with the mass center of robot, axis $C_1x_1$ is parallel to the side $A_1A_2$. The angle $\varphi$ defines the turn of the coordinates $Cx_1y_1$ about Oxy (see the figure 2). Let us consider that the body of a robot to be an absolute solid body being rectangular shape with the size $2a$ by $2b$, with mass of $m$ is in the center of symmetry $C$.

![Fig. 1. Schematic circuit of jumping robot: 1, 2, 3, 4 are joints of robot, 5 - rough surface; 6, 8 – actuators of rotation motion; 7 – actuator of linear motion](image1)

![Fig. 2. Loading diagram of the jumping robot](image2)
where \( \mu_v \) is coefficient of viscosity.

The main moment of force defined according to the equation 3:

\[
M_{\varphi} = \mu_f \ddot{\varphi},
\]

(3)

where \( \mu_f \) is coefficient of viscous resistance of robot body rotation

4. Differential Equations of Robot Movement

To organize the system of differential equations we’ll use Lagrange equation of second order. We will consider that masses of units 1, 2 and 3 are much smaller than the masses of unit 4 and their kinetic energy is equal to zero. After the corresponding transformations we will get the system of differential equations which describe the jumping robot parameters such as linear and angular acceleration of the center of robot body mass \( x_c, y_c, \dot{\varphi} \), normal reactions \( N_1 \) and \( N_2 \) in the support points \( A_1 \) and \( A_2 \) and the friction force \( F_{fr} \) in the point \( A_1 \).

\[
\dot{x}_c = \frac{1}{m} \left[ F_{fr} \cos(\alpha_{23}) - F_{23} \right], \quad \dot{y}_c = \frac{1}{m} \left[ F_{fr} \sin(\alpha_{23}) - F_{23} \right], \quad \dot{\varphi} = \frac{1}{J_c} \left[ M_{34} - 2 \mu_f R \dot{\varphi} \right],
\]

where \( J_c, J_1 \) are inertial moments of the body of a robot towards the points \( C \) and \( A_1 \).

4. Modelling of Robot Movement

The developed mathematical model helps in the research of jumping robot. During this research the influence of the value of the moment \( M_{34} \) and force \( F_{23} \) on the height and quality of the jump was examined. The quality of a jump is defined by the first point of landing and the second point of control which helps the robot to keep the balance. The height of a jump \( h \) is the distance along the vertical axis that mass center of the body reaches from the moment when \( y_1 = y \) till it reaches the maximum height. Let us describe the case when the line of active force \( F_{23} \) is going through the mass center of the robot body.

The modeling provided using following conditions: \( t=0, x_c=a, \dot{x}_c = 0, y_c=b, \dot{y}_c = 0, \varphi = 0, \dot{\varphi} = 0 \).

The parameters of the researched system: mass of the body \( m=10 \) kg, geometrical parameters \( a=0.25 \) m; \( b=0.15 \) m, inertial moments of the body towards the points \( C \) and \( A_1 \):

\( J_c=0.85 \) kg \cdot m\(^2\), \( J_1=1.7 \) kg \cdot m\(^2\), coefficient of sliding friction \( f=0.2 \).

The robot moves when the coefficient of viscosity of environment is equal to zero: \( \mu_v = \mu_f = 0 \) N \cdot s/m\(^2\).

As a result of numerical modeling the module dependencies of the force \( F_{23} \) from the height \( y \), during which the foot of a robot takes off the surface. The force stops its action. The mentioned graphics are in the picture 3 for the three constant heights of a jump for the moment \( M_{34}=26 \) Nm.
According to the picture we see that when the force $F_{23}$ increases the phase of acceleration changes into the phase of fly when the value $y$ is smaller this means that the length of the extended leg is shorter. It is fixed that this dependence is close to exponential.

The diagram of the jump in accordance to the moment $M_{34}$ when the force $F_{23}$ equal to 500 N is shown in the figure 4. It is seen in the picture that when the moment $M_{34}$ increases the rotational component of robot motion as a result the degree of rotation of the body against the clock also increases which leads to the change of the first point of landing of an object and the second point of area of bearing. On which the robot stands after the jump.

The diagram helps to define the range of values of the control torque $M_{34}$ during which the rational jump will be held. When the robot lands it touches point $A_1$ with the further turn of the object in clockwise order till it touches the area of bearing in the point $A_2$. Numerical value of $M_{34}$ doesn’t influence the height of the jump.

5. Conclusions

The scheme of 4-joints jumping robot is represented in the scheme. It is equipped with controlled electromechanical actuator. It imitates the jump of a frog or a grasshopper. Mathematical model is developed which contains the description of a system which shows the regularities of motion of jumping technical and biological systems and also practical recommendations for a jump.

The results of numerical modeling allow to define the character of the object motion in dependence to the control torque of the moments $M_{34}$ and force $F_{23}$. For the piecewise controlled laws of the parameters modification the following results were conducted. It was determined that when the moment $M_{34}$ increases the influence of rotation component of flat movement increases. The motion path of the robot during the fly, the point of landing of a robot changes, and also the second point of the area of bearing on which the robot turns when landing. The diagram defines the view of the flying path for the different values of control parameters.

The height of the jump $h$ is defined by the force $F_{23}$ and height $y$ where force $F_{23}$ is not active. When these parameters increase the robot jumps very high. If the height is fixed the value of the force $F_{23}$ slides down when $y$ increases according to the law similar to exponential.

References


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