Investigation Of Multi Joint Jumping Robot Movement

Jamil Al Azzeh [1], Ludmila U. Vorochaeva [2], Vadim V. Serebrovskiy [3] ,Ahmed A.M Sharadqeh [1] and Sergey F. Yatsun [2]

**[1] Computer Engineering Department, Al-Balqa Applied University
Amman, 302000, Jordan**

**[2] Department of Mechatronics, Southwest State University
Kursk, 305040, Russia**

**[3] Department of Applied Mathematics and Informatics, Southwest State University
Kursk, 305040, Russia**

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 pneumoelastic 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 α_{12} and α_{34} about axes H and A_1 and actuator 7 helps unit 4 to move about 3 under the action of force F_{23}.

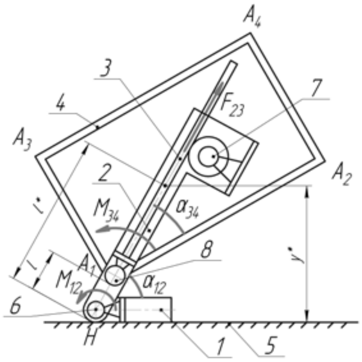

Fig. 1. Schematic circuit of jumping robot: 1, 2, 3, 4 are joints of robot, 5 - rough surface; 6, 8 – actuators of rotation motion; 7 –actuator of linear motion

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 he 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 α_{12} and α_{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 HH_1 and reaches point H_1 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 coinside 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 robot rotates till the second point of the body touches the surface that cause the jump ends.

3. Mathematical Model of a Robot

Let us introduce 2 coordinates systems: absolutely fixed Oxy and relative system Cx_1y_1which is connected with the body of robot so that the beginning of the coordinate C coincides with the mass center of robot, axis C_{x1} is parallel to the side A_1A_2. The angle φ 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.

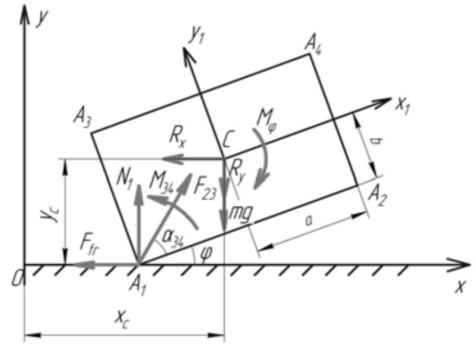

Fig. 2. Loading diagram of the jumping robot

Generalized coordinates of the robot defined by projections x_c and y_c of mass center position to the axis of absolute coordinate system and the angle φ of the robot body. Let us suppose that the jump of robot starts from initial position where the body of robot has a contact with rough surface in two points A_1 and A_2. The figure 2 shows that in the point A_1 during contact with surface there are forces of normal reaction N_1 and dry friction force F_{fr}, but in the point A_2 exists only force of normal reaction N_2. Motion of a robot begins in the moment of lift off of point H from the area of bearing so that if normal reaction N_H is equal to zero, the vertical coordinate of point A_1 reaches the value $y = L \cdot \sin\alpha_{12}$.

When the robot lands there is an inelastic impact and in the normal reaction force and rubbing friction. After which the body turns towards this fixed point 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:

$$F_{fr} = \begin{cases} fN_i \operatorname{sgn}(\bar{X}_i), \text{if } \bar{X}_i \neq 0; \\ F_o, \text{if } \bar{X}_i = 0, |\mathrm{F}_0| \leq \mathrm{fN_i}; \\ fN_i \operatorname{sgn}(F_0), \text{if } \bar{X}_i = 0, |\mathrm{F}_0| > \mathrm{fN_i}, \end{cases} \quad (1)$$

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; $\bar{X}_i$ - 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.

$$\bar{R} = \mu_v \bar{r}_c \, , \quad (2)$$

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where μ_v is coefficient of viscosity.

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

$$M_{\varphi} = \mu_{\varphi} \dot{\varphi}, \quad (3)$$

where μ_{φ} 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, φ, 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.

$$\dot{x}_c = \begin{cases} 0, \text{if} \left[\left[(N_1 > 0) \cap (\dot{x}_1 = 0)\right] \cap \left[((N_2 = 0) \cap (\dot{\varphi} = 0)) \cup (N_2 > 0)\right]\right], \\ \frac{1}{m}(F_{23} \cos(\alpha_{34} + \varphi) - F_{fr} - R_x), \\ \text{if} \left[\left[(N_1 > 0) \cap (\dot{x}_1 \neq 0)\right] \cup \left[(N_1 = 0) \cap (N_2 = 0)\right]\right] \\ -a\dot{\varphi}^2 \cos\varphi - a\ddot{\varphi} \sin\varphi + b\dot{\varphi}^2 \sin\varphi - a\ddot{\varphi} \cos\varphi, \\ \text{if} \left[(N_1 > 0) \cap (N_2 = 0) \cap (\dot{x}_1 = 0) \cap (\dot{\varphi} \neq 0)\right] \end{cases} \quad (4)$$

$$\dot{y}_c = \begin{cases} 0, \text{if} \left[(N_1 > 0) \cap \left[(N_2 = 0) \cup \left[(N_2 > 0 \cap (\dot{\varphi} = 0)\right]\right]\right], \\ \frac{1}{m}(F_{23} \sin(\alpha_{34} + \varphi) - mg - R_y), \text{if} \left[(N_1 > 0 \cap (N_2 = 0)\right] \\ -a\dot{\varphi}^2 \sin\varphi - a\ddot{\varphi} \cos\varphi + b\dot{\varphi}^2 \cos\varphi - b\ddot{\varphi} \sin\varphi, \\ \text{if} \left[(N_1 > 0) \cap (N_2 = 0) \cap (\dot{\varphi} \neq 0)\right] \end{cases} \quad (5)$$

$$\ddot{\varphi} = \begin{cases} 0, \text{if} \left[(N_1 > 0) \cap \left[((N_2 = 0) \cap (\dot{\varphi} = 0)) \cup (N_2 > 0\right]\right] \\ \frac{1}{J_c}(M_{34} - M_{\varphi} - aN_1\cos\varphi + bN_1\sin\varphi - bF_{fr}\cos\varphi - aF_{fr}\sin\varphi + \\ + bF_{23}\cos\alpha_{34} - aF_{23}\sin\alpha_{34}), \text{if} \left[(N_1 > 0 \cap (N_2 = 0)\right] \cup \\ \cup \left[(N_1 > 0 \cap (N_2 = 0) \cap (\dot{x}_1 \neq 0) \cap (\dot{\varphi} \neq 0)\right] \\ \frac{1}{J_c}(M_{34} - amg\cos\varphi + bmg\sin\varphi + bR_x\cos\varphi + \\ + aR_x\sin\varphi - aR_y\cos\varphi + bR_y\sin\varphi - M_{\varphi}), \\ \text{if} \left[(N_1 > 0) \cap (N_2 = 0) \cap (\dot{x}_1 = 0) \cap (\dot{\varphi} \neq 0)\right] \end{cases} \quad (6)$$

$$N_1 = \begin{cases} \frac{mg}{2} - F_{23}\sin\alpha_{34} + \frac{bR_x + M_{34}}{2a}, \text{if} \left[(y_1 = 0) \cap (y_2 = 0)\right], \\ m\ddot{y}_c + mg - F_{23}\sin(\alpha_{34} + \varphi) + R_y, \\ \text{if} \left[(y_1 > 0) \cap (y_2 > 0)\right], \\ 0, \text{if} (y_1 > 0) \end{cases} \quad (7)$$

$$N_2 = \begin{cases} \frac{mg}{2} - \frac{M_{34}}{2a} - \frac{bR_x}{2a}, \text{if} \left[(y_1 = 0) \cap (y_2 = 0)\right], \\ 0, \text{if} (y_2 > 0) \end{cases} \quad (8)$$

$$F_{fr} = \begin{cases} -m\ddot{x}_c + F_{23}\cos(\alpha_{34} + \varphi) - R_x, \\ \text{if} \left[(N_1 > 0) \cap (\dot{x}_1 = 0)\right], \\ fN_1 \operatorname{sgn}(\dot{x}_1), \text{if} \left[(N_1 > 0) \cap (\dot{x}_1 \neq 0)\right], \\ 0, \text{if} \left[(N_1 > 0) \cap (N_2 = 0)\right], \end{cases} \quad (9)$$

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=0.15m, 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: $\mu_v = \mu_{\varphi} = 0\ N \cdot s/m^2$.

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.

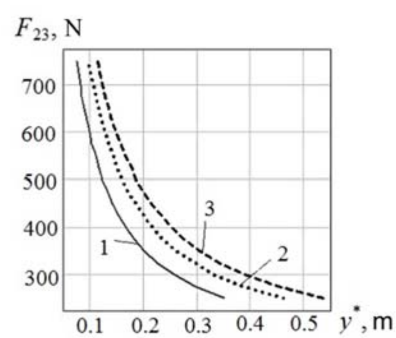

Fig. 3. Relation between force F_{23} and y^* for different jump height: 1. for h=0.4 m, 2. for h=0.5 m, 3. for h=0.6 m.

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 M34 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.

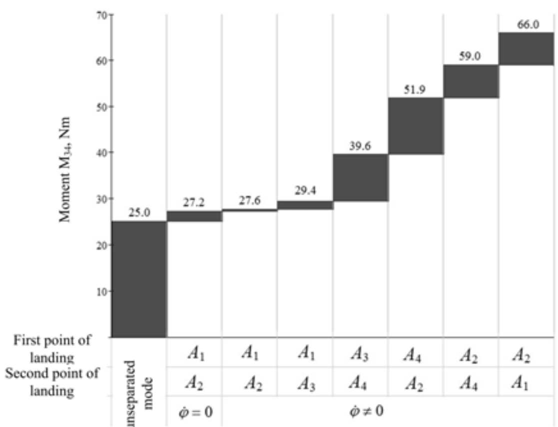

Fig.4. The diagram of robot jump created for different values of M_{34}

The diagram helps to define the range of values of the control torque M34 during which the rational jump will be held. When the robot lands it touches point A1 with the further turn of the object in clockwise order till it touches the area of bearing in the point A2. Numerical value of M34 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.

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First Author **Dr. Jamil S. Al-Azzeh** received his PhD Degree in Computer Engineering from Saint Petersburg Sate University – Russia in 2008. Since 2008, Dr. Al-Azzeh has been an assistant professor in the Computer Engineering Department, Faculty of Engineering Technology, at Al-Balqa' Applied University. His research interests include image processing. FPGA, digital systems design, network operating system, and Microprocessors.

Ludmila U. Vorochaeva is assistant of Theoretical Mechanics and Mechatronics Departmant of Southwest State University. From 2011 she is lecturer of this university, from 2014, she has assigned to position of senior lecturer. In 2014, she was awarded the academic rank of Ph.D. in the specialty "Dynamics and Strength of Machines, Devices and Equipment". Scientific interests of Dr. Ludmila are simulation of mechatronics systems, multi-link systems, mechatronics, robotics. Dr. Vorochaeva is the author of over 40 scientific works, co-author of 2 monographs and co-author of 5 patents.

Vadim V. Serebrovskiy is PhD from 1999, Doctor of Science from 2009, Full Professor of the Department of Informatics and Applied Mathematics from 2013. Currently he is corresponding member of the Russian Academy of Natural Sciences. He had been working in the Kursk Agricultural Academy from 1994 to 2010, currently he is the head of Computer Science and Applied Mathematics Department of Southwest State University, Kursk, Russia. He is the chairman of the jury of student and post-graduate student competitions in computer science and information technology in Belgorod State University. He is a key person of grants on the subjects like: Development of information system of forming multimedia interactive educational environment of the distributed class, Development of access services for broadband multimedia services in educational environment of the university, hi is also actively involved in other research studies in the field of education. He has been the Head of a center of interactive e-learning for 3 years. He has over 90 publications in the field of information technologies in science and education, restoration of machine parts.

Sergey F. Yatsun started his scientific activity as a Junior researcher in the Dnepropetrovsk city in the Mountain Institute, then he entered the postgraduate courses. In 1979 he has accepted the Ph.D. level in Michalicka Technical University (Hungary). In 1982 Sergey awarded the academic title of Associated Professor, in 1990, prepared and defended his doctoral dissertation in Riga Technical University. Since 1989 he is head of Theoretical Mechanics and TMM department of the Kursk State Technical University. In 1992 he received the academic title of of Full Professor. Scientific interests of Sergey Yatsun located in such fields as vibration machines and technologies, dynamics and strength of machines, theory of automatic control, mechatronics and robototehnics. Sergei F. Yatsun is author and co-author of 12 monographs and more than 250 scientific works. He has received about 120 author's certificates and patents.

Dr Ahmed A.M Sharadqeh: received his PhD Degree in Computer, computing system and networks from National Technical of Ukraine "Kyiv Polytechnic Institute – Ukraine in 2007. Since 2009, Dr. Ahmed sharadqh has been an assistant professor in the Computer Engineering Department, Faculty of Engineering Technology, at Al-Balqa' Applied University. His research interests include Performance of network, Artificial Intelligence and Intelligent Agents Networking and Performance Evaluation.