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Design of a special cam-based high speed manipulator system

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Abstract: In this paper, we develop a mechanism that mainly used a special cam and gearbox to utilize a DC servo motor powerfully and speedily for a linkage manipulator. The mechanisms can be charged slowly, store the energy in a spring and release it on demand using a click mechanism. By compared the motions with many cams, we designed our special cam that can output an explosive movements. Two torsion springs, used as elastic elements, are located on the manipulator axis which is connected to the main link and the mechanism. Consider about the output of a manipulator, we choose to implement a four bar linkage design for the motion and force control. The manipulator's mathematic models are built for purposed of analysis and control.

Keywords: High-speed manipulator, series-elastic actuation (SEA), five bar linkage, explosive movements.

1 INTRODUCTION

Since robots work in place of humans in many fields, the developing of high-performance robots has increased rapidly, such as those in industry fields, automobile assembly plants, precision works, etc. Depends the development of multiple motors, about the high speed robot, one interesting and challenging research topic is the energy saving problems.

However, multitudinous of techniques are proposed in many aspect to achieve the high speed motions. For a manipulator, the motion of high-speed could consist of three patterns, 1) Fast-forward (FF); 2) Fast-reverse (FR); 3) Fast forward and reverse (FFR). There is a developed golf robot [1] whose swing simulates human motion is proposed in order to reach ultra Fast-forward speed. Imitate to human motion ability, this robot consists of a shoulder joint with a high-power direct-drive motor and a wrist joint with a low-power direct-drive motor to realize ultrahigh-speed dynamic manipulation using a dexterous mechanism. The most representational Fast-reverse technique is utilized in jumping robot. It is generally known that the high power humanoid is desired for application of running or jumping motions. The dynamic motion of jumping is characterized by large instantaneous forces and short duration [2], depends of those conditions, some jumping structures used springs both in improve the velocity and energy conservation [3]. The crucial factor in a high speed manipulator is the motor.

There is a relatively large robots related to using high-speed mechanisms or methods for manipulators for different applications and different scales. In the following subsections, we will review the principles of how these existing robots address the challenges of high-speed problem in manipulators.

By the literature survey the general classification is given in Fig. 1. Five common high-speed structures are introduced in this figure, (i) the spring systems [4], (ii) the cam system [5], [6], (iii) four-bar spring linkage system [5], [7], (iiii) the electric system [8], (iiiii) hydraulic system. Every structure has their advantages and disadvantages. The most skillful spring system is applied in gums, combine of kinds of springs and the bullet,

2 DESIGN OF HIGH-SPEED MANIPULATOR

The driving principle of this system is described.

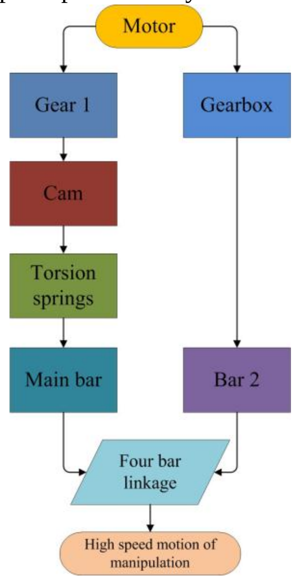


Fig. 1. The illustration of motion flow chart

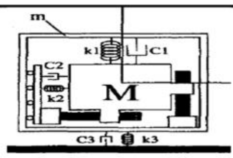
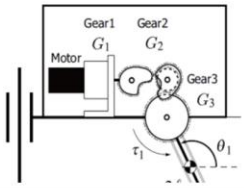
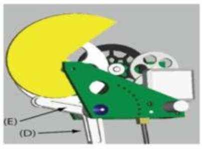
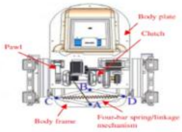
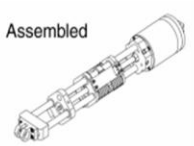
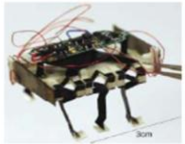
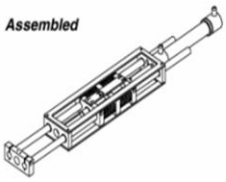
High-speed structure	Advantage	Disadvantage	The figures of existing structure	
Spring system	Simple construction Low cost, Energy saving Light weight	Nonlinear control		
Cams system	Construction simple Realize high speed motion, Motion can stack up	Easy abrade Short journey distance Invariance time/angel Processing difficulty		
Four-bar spring-linkage system	Small abrade Easy fabrication High precision	Trajectory fixed High speed will cause the large vibration, Design Complexity		
Electric system	Easy to control Variance time or angle Light weight	Energy-intensive		
Hydraulic system	Regulation of output	Finishing movement has big impulsion, Complicated structural. Big size/volume High cost		

Fig. 2. Classification of the existing high-speed manipulators

2.1 Mechanical design

The mechanisms can be charged slowly, store the energy in a spring and release it on demand using a click mechanism. This mechanical principle is used by several small animals and insects**.**

By compared the motions with many cams, we designed our special cam that can output an explosive movements. The manipulator, consisting of a four bar linkage structure connected by springs and travels quickly using this special cam that is mounted on actuator which are connect by gears. The shape of the cam has been specifically designed to yield a constant torque on the motor through a three stage gearbox system.

Two torsion springs, used as elastic elements, are located on the manipulator axis which is connected to the main link and the mechanism. To charge these two springs, a small DC motor actuates the special cam and rotates the main link lever manipulator by a constant angle (can been calculate by the given cam parameters) for one charge cycle.

Consider about the output of a manipulator, we choose to implement a four bar linkage design for the motion and force control. Using this design offers the possibility to modify the rotating angle by adjustment the parameters of the special cam and the trajectory of the manipulator tip by adjustment of the gear ratio.

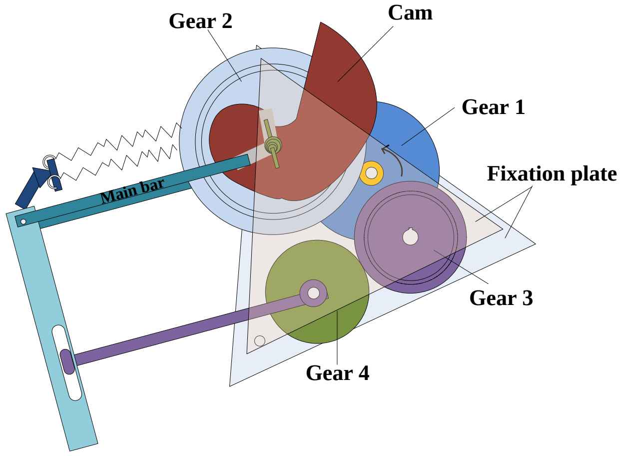


Fig. 3. The mechanical design of the high speed structure.

The structure for connect the main link and the torsion springs:

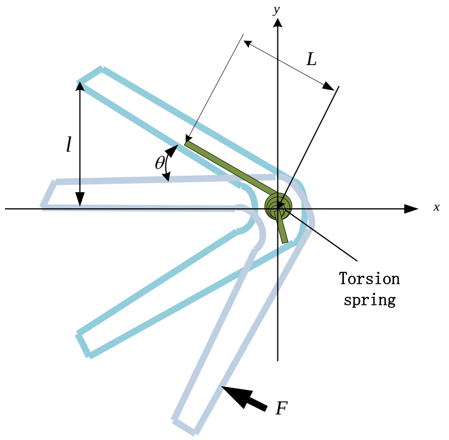


Fig. 4. The torsion spring fixing mechanism

2.2 Kinematic model

Mechanical design and kinematic analysis are introduced in this paper.

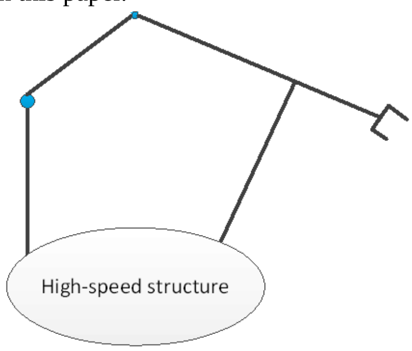


Fig. 5. The kinematic model of the high speed structure.

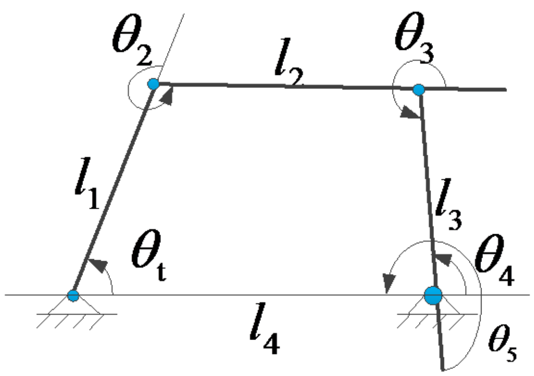


Fig. 6. The four bar linkage structure.

For the input of the motor, we have :

$$\omega_2 = \frac{R_1 z_1}{z_2}\omega_m \Rightarrow \dot{\underset{\rightarrow}{\phi}}_2 = \frac{R_1 z_1}{z_2}\omega_m \tag{1}$$

For the gear1 and gear2, we get:

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \cos(Iw \bullet \phi) & -\sin(Iw \bullet \phi) \\ \sin(Iw \bullet \phi) & \cos(Iw \bullet \phi) \end{bmatrix} \begin{bmatrix} S_o + S \\ e \end{bmatrix} \tag{2}$$

S_0, S and e are parameters of cam.

If clockwise, $Iw = +1$; anticlockwise, $Iw = -1$.

k_1 and k_2 are parameters of torsion spring.

For the Torsion springs, we know that

$$\underset{\rightarrow}{\theta_t} = \frac{F}{k_1}\begin{bmatrix} x \\ y \end{bmatrix} = \frac{k_2}{k_1}\begin{bmatrix} (S_o + S)\cos(Iw \bullet \phi) & -e\sin(Iw \bullet \phi) \\ (S_o + S)\sin(Iw \bullet \phi) & e\cos(Iw \bullet \phi) \end{bmatrix} \underset{\rightarrow}{\phi} \tag{3}$$

Where, the force is calculated

$$F = k_2 \underset{\rightarrow}{\phi} \tag{4}$$

So, we get:

$$\begin{aligned} \dot{\underset{\rightarrow}{\theta}}_t &= \frac{k_2}{k_1}\begin{bmatrix} x \\ y \end{bmatrix}\dot{\underset{\rightarrow}{\phi}} + \frac{k_2}{k_1}\underset{\rightarrow}{\phi}\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} \\ &= \frac{k_2}{k_1}\begin{bmatrix} (S_o + S)\cos(Iw \bullet \phi) & -e\sin(Iw \bullet \phi) \\ (S_o + S)\sin(Iw \bullet \phi) & e\cos(Iw \bullet \phi) \end{bmatrix} \underset{\rightarrow}{\phi} \bullet \dot{\underset{\rightarrow}{\phi}} \\ &+ \frac{k_2}{k_1}\underset{\rightarrow}{\phi}\begin{bmatrix} -(S_o + S)\sin(Iw \bullet \phi) & -e\sin(Iw \bullet \phi) \\ (S_o + S)\cos(Iw \bullet \phi) & e\sin(Iw \bullet \phi) \end{bmatrix} \dot{\underset{\rightarrow}{\phi}} \end{aligned} \tag{5}$$

2.3 Dynamic model

The manipulator's mathematic models are built for purposed of analysis and control. The dynamic model is built and many simulation models are built for testing the velocity and explosive force of the manipulator.

Suppose the system is in balance, we have,

$$\underset{\rightarrow}{T_t^*} = \underset{\rightarrow}{0} \tag{6}$$

In this redundant actuator system, suppose there are two independent joint 1 and 4, the equation between the independent joint and the dependent joint is:

$$\underline{\dot{\phi}_P} = \left[G_a^P\right]\underline{\dot{\phi}_a} \tag{7}$$

The equation of the dynamic model as,

$$\begin{bmatrix} 1 & g_4^t \\ 0 & -h_{tt}^4 \end{bmatrix}\begin{pmatrix} T_t \\ T_4 \end{pmatrix} = \begin{pmatrix} T_t^* \\ 0 \end{pmatrix} \tag{8}$$

Here,

$$\begin{aligned} \left[G_a^P\right] &= \begin{bmatrix} g_t^2 \\ g_t^3 \\ g_t^4 \end{bmatrix} \\ &= \frac{1}{l_2 l_3 \sin_3}\begin{bmatrix} -l_3 l_4 \sin_{t+2+3} \\ l_4(l_2 \sin_{t+2} + l_3 \sin_{t+2+3}) \\ l_2(l_3 \sin_3 + l_4 \sin_{t+2}) \end{bmatrix} \end{aligned} \tag{9}$$

$$\begin{aligned} h_{tt}^4 &= \frac{\partial}{\partial \theta_t}(g_t^4) \\ &= \frac{l_4 \cos_{t+2}(1 + g_t^2)\sin_3 - l_4 \sin_{t+2}\cos_3 g_t^3}{l_3(\sin_3)^2} \end{aligned} \tag{10}$$

The testing results show that the requirements with respect to velocity, acceleration, working space and energy are successfully achieved.

3 CONCLUSION

This mechanism witch is designed to be characterized as high speed manipulator could also form the propulsion system of a jumping robot or be used for self deployment of sensors. Our future research can combining some more degree of freedom manipulator and developed as a biomimetic arm that may attach more applications.

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REFERENCES

[1] Maruyama T, Xu CQ, Ming A and Shimojo M (2006), Motion Control of Ultra-High-Speed Manipulator with a Flexible Link Based on Dynamically Coupled Driving, Journal of Robotics and Mechatronics, Vol. 18, No.5, pp.598-607

[2] Urata J, Nakanishi Y, Okada K and Inaba M (2010), Design of High Torque and High Speed Leg Module for High Power Humanoid, in Proceedings of International Conference on Intelligent Robots and Systems, pp. 4497-4502

[3] Wang M, Zang XZ, Fan JZ and Zhao J (2008), Biological Jumping Mechanism Analysis and Modeling for Frog Robot, pp.181-188

[4] Shimoda S, Kubota T and Nakatani I (2002), New Mobility System Based on Elastic Energy under Microgravity. in Proceedings of International Conference on Robotics and Automation, pp. 2296-2301

[5] Mirko K, Martin F, Andr G, et al (2008),A miniature 7g jumping robot, in Proceedings of International Conference on Robotics and Automation, pp.373-378

[6] Okada M and Murakami K (2007), Robot Communication Principal by Motion Synchronization using Orbit Attractor, pp. 2564-2569

[7] Reddy N. S., Ray R, Shome S.N. (2011), Modeling and Simulation of a Jumping Frog Robot, in Proceedings of International Conference on Mechatronics and Automation, pp.1264-1268

[8] Jerry E. Pratt, Benjamin T. Krupp (2004), Series Elastic Actuators for legged robots, Storage and Retrieval for Image and Video Databases,

