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A NEW CONCEPTUAL DESIGN SCHEME FOR THE ELBOW JOINT OF NURSING ROBOT ARM

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Abstract

Unlike an ordinary hinge joint used in robot arm, this paper presents a new conceptual design scheme for the elbow joint of a nursing robot arm. A special torque-balancing mechanism and energy-storage part are introduced into this new type of joint. The energy-storage part provides an internal torque to balance the torque on elbow joint due to the weight of forearm through a special torque-balancing mechanism.

Introduction

Two of the basic requirements for a nursing robot arm are motion stability with low noise and an adequate load-lifting capability with small size. In order to meet these requirements researchers have been trying a lot of efforts to develop better arm controllers[1,2], different motion patterns[3], new type of joint dampers[4], and a lot of others' creative works that can not be listed here due to page limitation. All these researches show that it is a comprehensive problem and needs further efforts. This paper presents another possible alternative approach to improve the dynamic performance and to enhance the load-lifting capability of a nursing robot arm being developed in Tsinghua University in a different way. The nursing robot is expected to design as a mobile robot with 6 DOF arm.

Generally the elbow joint of a nursing robot arm is designed as a hinge joint attached an electrical actuator. However, because this joint bears a great torque due to the length of forearm, the load-lifting capability of nursing robot arm is usually very weak. Furthermore the impact as locking or unlocking this joint makes the dynamic performance unsatisfactory. For solving this problem, one question is under our consideration. Is it effective or helpful if an energy storage part and a special torque-balancing mechanism introduced into the joint? This paper will give a brief discussion of this question. Actually a similar structure was adopted in our newly developing intelligent prosthetic elbow joint. It was preliminarily evaluated effective[5,6].

Conceptual Design Scheme

Basic considerations

The functions of energy-storage part and of torque-balancing mechanism should cover the two basic requirements mentioned in last section. That means they could (1) attenuate the impact as unlocking or locking the elbow joint to improve the dynamic performance of nursing robot arm and (2) balance the torque on the elbow joint caused by the weight of forearm to increase its load-lifting capability. From the viewpoint of mechanical design a spring-like energy-storage part could fulfill the first function and a special transmission mechanism could accomplish the second function. The two basic ideas form the new conceptual design scheme for the elbow joint of a nursing robot arm.

Design diagram

Figure 1 shows its main parts of the new type of elbow joint of a nursing robot arm. Element 1 & 2, the non-circular gears or other equivalents, are employed. Part 3, the energy-storage part,

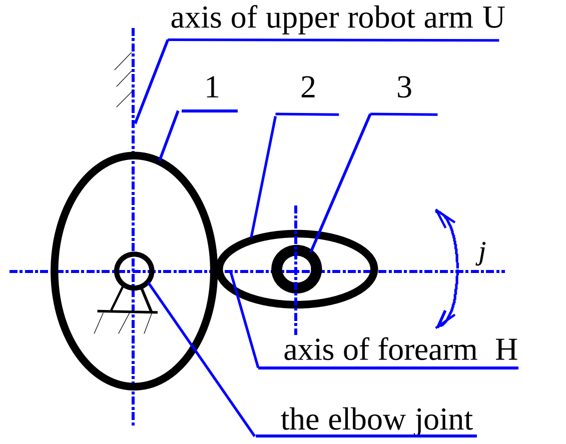

Figure 1 Conceptual design scheme

could be spring-like elements or other equivalents, which provide an internal torque to balance the torque caused by the weight of forearm.

The first glance at the design diagram it seems that it will cost too much space occupation and joint weight. But after careful design this cost is acceptable. More important it will give many more benefits to overall system.

Design objective

In the conceptual scheme illustrated in figure 1, if spring-like elements are adopted, the main design objective equation considering statics and kinematics is as below,

$$P \bullet L \bullet Sin(j_U + j_H) = K(P) \bullet \left[\Phi_0^H + \int_0^{j_H} i^H(j_h)\,dj_h\right] \bullet i^H(j_h) \qquad (1)$$

where, P is the equivalent load acting at the end of robot arm, L is the fore-arm's length, j_U is the angular position of the upper-arm, j_H is the relative angular position of the arm to the upper-arm, K is the stiffness of energy-storage element, $F_0{}^H$ is the angle of pretension, $i_{12}{}^H$ is the transmission ratio from element 1 to element 2 in the moving reference coordinate system H, j_H is the relative angular displacement of fore-arm. Other governing equations are omitted here due to page limitation.

From equation (1) we can see that if to fully satisfy this equation will lead to a very complicated mechanism design, because it has three variables (P, j_U, j_H) to define the characteristics of transmission mechanism and energy-storage part. But a complicated structure can not be accepted here. So, we have to lower our expectation. As a preliminary approach the following assumptions can be adopted, (1) the load *P* is considered as the equivalent load acting at the end of robot arm due to the weight of fore-arm itself; (2) the upper-arm position is assumed at the natural vertical line. And then the structure design can be accomplished. The overall size can be limited in a desirable dimension, which diameter will be less than 60mm in our preliminary design.

Performance Prediction and Discussions

Load-lifting capability

One advantage of the new design scheme is that it has a higher load-lifting capability. That is because an energy-storage part is introduced into the joint, which can absorb the gravity potential of the robot fore-arm as it moves down, and give out the stored energy to help rotating the robot fore-arm as it moves up. If the robot fore-arm has an equivalent weight 6N (assumed acting at the end of the arm), the internal torque provided by the energy-storage part can balance the torque due to the weight of forearm itself on elbow joint with the special torque-balancing mechanism. Consequently the externally electrical actuator can lift more 6N object than the robot arm without mounting energy-storage part and torque-balancing mechanism. Since large motor is not suitable for mounting on the joint of robot arm, not like an industrial robot arm, the load capacity of electrical actuator used in nursing robot is not great. Even if this is within its load capacity, electrical motor will work in a better condition because it works under a relatively low external load. On the other hand, it also means the robot fore-arm can balance at any angular position under no external load condition. This will bring a great benefit for robot arm's gesture control. So, this additional load-lifting capability is of great significance.

However these discussions are based on the assumption that the upper robot arm is located at or near the natural vertical line. If the upper robot arm rotates to another angular position, the torque balance condition will be changed. The unbalanced torque on the elbow joint, *DT*, can be expressed as follow,

$$DT(j_U, j_H) = P \cdot L \cdot Sin(j_U + j_H) - T_S(j_H) \qquad (2)$$

where $T_S(j_H)$ is the internal driving torque from the energy-storage part. At this occasion the unbalanced torque *DT* is a two variables' function. It means that a 2 DOF automatic adjustable mechanism is required, which is under our consideration. Or it should be driven by externally powered motor.

Dynamic performance

The energy-storage part not only acts as an energy absorbing and energy giving out member, but also acts as a load buffer like a spring-biased mechanism used in Utah arm [7]. Especially as unlocking the elbow joint, the impact load that is a disaster to dynamic performance can be absorbed by the energy-storage part. Otherwise the instant peak current in motor will be very high. From this point this new conceptual design will improve the dynamic performance of nursing robot arm and make it easier to control. In order to obtain a robust optimum performance, however, a more accurate dynamic design model, in which both the electric control system and the mechanical system must be all considered together, is still needed. Otherwise the ideal performance is still an imaginative drawing. Due to page limitation more detailed and quantitative analyses can not be discussed here.

Conclusion

With a better mechanism a more ideal dynamic performance can be obtained with less effort. From the qualitative analyses and discussions in this paper the new conceptual design scheme for the elbow joint of nursing robot arm is a promising way to reach this goal. Because the energy-storage part, which possesses both an energy-storage function and a load buffer function, and a special torque-balancing mechanism, which can partially balance the torque on elbow joint, are introduced into the new design scheme, the new type of joint may be an alternative effective way to improve the dynamic performance and to enhance the load-lifting capability of a nursing robot arm. But further quantitative design, analysis, and experiment are still needed.

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