

FORCE LIMITATION WITH AUTOMATIC RETURN MECHANISM FOR RISK REDUCTION OF REHABILITATION ROBOTS

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Abstract

In this paper, a new mechanism to reduce the risk of rehabilitation robots contacting the human body is proposed. It was composed of a force limitation mechanism and a soft structure with anisotropic viscosity. A prototype was developed, and its basic features were experimentally evaluated. The size of the prototype was too big, but it was confirmed that the new mechanism had many advantages. It could avoid a stronger force than a threshold level would affect a person. As the arrangement of the mechanism was not restricted to the robotic joints, the effect of posture of a robot upon the limitation force was able to be reduced to a certain degree (although not entirely). And, because elastic energy was consumed in the return process, it would not resonate.

Introduction

Lately rehabilitation robots have become of general interest. However, there are very few reports on how to reduce the risk of rehabilitation robots hitting humans. Because robots are essentially dangerous, industrial robots must be used in isolation from human work spaces. Contrary to this, rehabilitation robots cannot be separated from human work spaces because of their purposes. As a

basic solution to this problem, a new risk reduction strategy for rehabilitation robots must be formulated to prevent accidents.

Solutions to this problem have been previously suggested. The method by which a robot stops by ultrasonic or beam sensor signals before contact with a human body is unreliable [1][2]. Losing dead angles of the sensing area is difficult in this method. It can be considered that this is an additional method for risk reduction. As another method, force sensors and torque sensors were suggested to detect contacts [3]. However, problems lie in low reliability caused by intolerability of electronic devices to electromagnetic noise. Soft mechanisms, such as soft arms, soft joints or soft covers, feature to reduce the peak of impulsive force [4]. However, no report has clarified the most suitable compliance values. If a soft system such as a whip is resonant, it may be dangerous. It is also a problem that a soft structure is deformed even by a weak force. As practical solutions for a simple system, force (or torque) limitation mechanisms and small power actuators are suggested [5]. However, deciding the limitation torque value for an articulated robot is a difficult planning problem

because of its complex relationship between torques and an external force.

Every method has its merits and demerits. In the present situation where a proper countermeasure cannot be found, it is difficult to make the use of rehabilitation robots widespread. The purpose of this study was to develop a new risk reduction mechanism that combines the advantage of a soft structure and a force limitation mechanism.

Design Rationale

A new force limitation mechanism was proposed. A force limitation mechanism is rigid against weaker forces than a threshold, but it is activated to move or to slip by stronger forces. It can protect a user against excessive forces from a robot. However, previous force limitation mechanisms could not return by themselves after releasing forces. They were restricted to be arranged on joints of articulated robots because their return movements were produced by actuators that drove the joints. If force limitation mechanisms can automatically return after releasing force, it becomes possible freely to arrange them on any part of the robot arm. It will be easier to decide the limitation force value and it will lead to new possibilities for the force limitation mechanism accordingly. Careful consideration should be given to a mechanical impedance of the return mechanism; If viscosity is set low when the mechanism operates under excessive forces, rapid responses to excessive

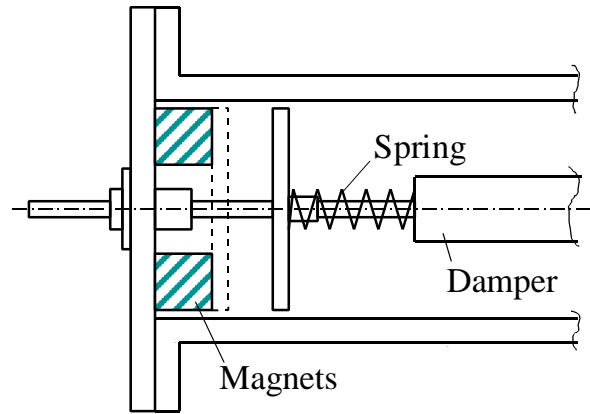


Figure 1 Structure of a prototype of a force limitation with automatic return mechanism.

Table 1 Feature of the damper

Damper Type	ADA510MTP
Stroke	100mm
Max. Load	2000N
Speed(compress)	0.47m/s(500N)
Speed(extend)	0.03m/s(500N)

forces will be available. On the other hand, high viscosity on the return will avoid the resonant problem. The mechanism should have anisotropic viscosity after all.

Development

A prototype of this mechanism was developed to confirm its features (see Figure 1). The total size was 400 mm in length and 200 mm in diameter. A commercial damper (Enidine ADA510MTP) with anisotropic viscosity was used. The viscosity of the damper in extension, which was adjustable, was set at the highest value. Features of the damper are shown in Table 1. Two types of mechanical spring for generating the

return movement were prepared: spring type I had a stiffness of 2900 N/m and was fixed with a pre-load of 58 N, and spring type II had a stiffness of 4900 N/m and was fixed with a pre-load of 98 N. Force limitation was realized by four or five magnets, each of which had an ideal holding force of 98 N with steel. The straight movement was supported by a ball bearing.

Methods

A total of four prototypes of two kinds of spring and two kinds of magnet were examined by static forces. Each prototype was rigid against weak forces, but was activated to move by strong forces. Results of the threshold force are shown in Table 2. The threshold force was adjustable by the magnets and the spring. However, the results obtained did not agree with the theoretical results. The standard deviations were so wide as to be 3%, but I think that they were permissible because the diversities of a human are wider. The factors affecting it could be friction, the dead load, the unbalanced load, the flatness and the quality of the steel. This will be improved by introduction of a stiffer bearing system. The travel of the mechanism was measured with a laser displacement sensor (Keyence LK-2500) when a force was given and released statically. The constant force for the experiment is shown in Table 3.

Results

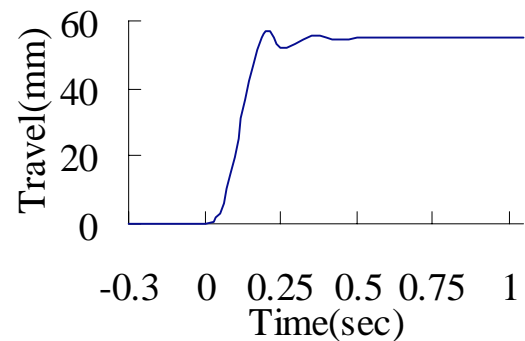
A typical example of the results is shown

Table 2 Results of threshold force

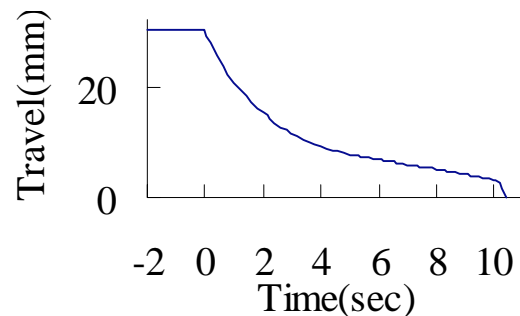
Magnets	Spring type I	Spring type II
4	229.1±7.4[N]	283.0±8.5[N]
5	318.6±9.6[N]	371.1±4.9[N]

Table 3 Loads for travel measurement

Magnets	Spring type I	Spring type II
4	230[N]	330[N]
5	330[N]	430[N]



(a) Forward movement



(b) Return movement

Figure 2 A typical result of travel measurement (five magnets and spring type I).

in Figure 2. The results obtained agreed approximately with those expected. When the force was given, the mechanism was started immediately and it traveled 55 mm within 0.25 seconds.

On the other hand, the mechanism returned slowly after release. Time constants of the return were 3.4 seconds for spring type I and 2.4 seconds for spring type II, which were long enough to avoid resonance. On the last two or three millimeters of movement, the mechanism quickly returned by the magnetic force, but this would not be a disadvantage of the mechanism. The distance of the quick movement was determined by the force of the spring and the magnets.

A two-dimensional application model by which a force is given to a robotic link with two moment limitations with automatic return mechanisms is shown in Figure 3. Although the prototype moved straight, a rotation type was used in the simulation. When the threshold moment at mechanism A is M_{Amax} and one at B is M_{Bmax} , the external force F is limited as follows:

$$F \leq \left| \frac{M_{A \max}}{l_1 \sin \theta} \right| \quad \text{and} \quad F \leq \left| \frac{M_{B \max}}{l_2 \sin(\theta + \alpha)} \right|$$

A typical result of the simulation is shown in Figure 4. The force is limited as the thick line by two mechanisms. Because the threshold force is finite at any angle, the contact force can be limited in a certain range independently of the posture of the robot. As the result of simulation, a free arrangement of the mechanism will bring various advantages.

Discussion

To be applied to rehabilitation robots, the

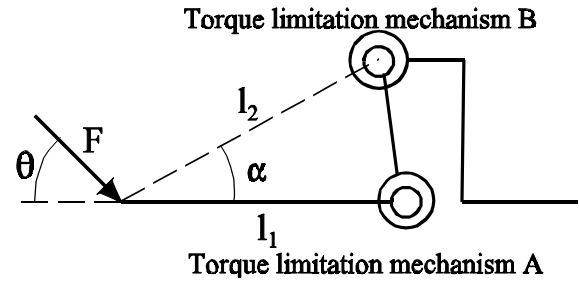


Figure 3 A two-dimensional model of a robot arm with torque limitation mechanism.

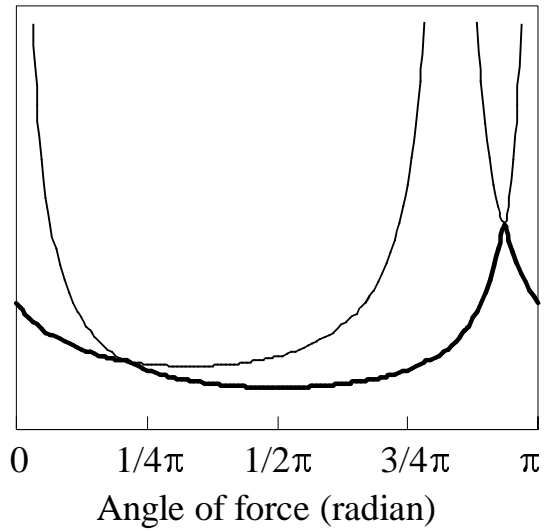


Figure 4 Result of simulation of the model.

mechanism should be reduced to a size of 50-100 mm and a threshold force of 50-100 N. However, I believe that I showed this new idea to be beneficial. Being miniaturized by developing a small damper would be possible instead of a commercial one in which viscosity was adjustable. The viscosity, the stiffness and the threshold force value should be considered for a rehabilitation robot experimentally. There will be a better arrangement than the simulation by using three or more moment limitation mechanisms. It is easy to expand to a three-dimensional model. It would also

be applicable to an anisotropic force limitation mechanism.

Conclusion

A prototype of a new mechanism to reduce the risk of a rehabilitation robot hitting the bodies was developed. It was confirmed that the new mechanism had many advantages, such as a flexible arrangement, and no resonance. Miniaturization and a way to determine parameters will be subjects for future study.

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References

- [1] M. Kioi, S. Tadokoro, T. Takamori: A Study for Safety of Robot Environment; Proc. 6th Conf. Robotic Soc. Japan, 393-394(1988)(in Japanese)
- [2] H. Tsushima, R. Masuda: Distribution Problem of Proximity Sensors for Obstacle Detection; Proc. 10th Conf. Robotic Soc. Japan, 1021-1022(1992) (in Japanese)
- [3] K. Suita, Y. Yamada, N. Tsuchida, K. Imai: A study on the Detection of a Contact with a Human by a Compliance-Covered Robot with Direct Torque Detection Function ~In Case of 1 Link Robot; Proc. ROBOMECH'94, 897-902(1994) (in Japanese)
- [4] T. Morita, N. Honda, S. Sugano:

Safety Method to Achieve Human-Robot Cooperation by 7-D.O.F. MIA ARM - Utilization of Safety Cover and Motion Control -; Proc. 14th Conf. Robotic Soc. Japan, 227-228 (1996) (in Japanese)

[5] T. Saito, N. Sugimoto: Basic Requirements and Construction for Safe Robots; Proc. ROBOMECH'95, 287-290(1995) (in Japanese)

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