The Eighteenth International Symposium on Artificial Life and Robotics 2013 (AROB 18th '13),
Daejeon Convention Center, Daejeon, Korea, January 30-February 1, 2013

Design of a rehabilitation robot suit with hardware-based safety devices - Proposal of the basic structure -

Yoshihiro Kai[1], Satoshi Kitaguchi[1], Wenlong Zhang[2] and Masayoshi Tomizuka[2]

[1] Tokai University, Japan
[2] University of California, Berkeley, USA

[1]kai@tokai.ac.jp

Abstract: Safety is one of the most important issues in rehabilitation robot suits. We present a new rehabilitation robot suit equipped with two hardware-based safety devices. The robot suit assists a patient's knee joint. The safety devices consist of only mechanical components without actuators, controllers, or batteries. We expect that the safety devices guarantee the safety even if the computer does not work. We call one device the "velocity-based safety device" and the other device the "torque-based safety device". The velocity-based safety device can switch off the motor of the robot suit if the device detects an unexpected joint angular velocity. Also, the torque-based safety device can switch off the motor if the device detects an unexpected joint torque.

Keywords: Human-machine cooperative systems, Human-welfare robotics, Rehabilitation robot, Robot suit, Safety device.

1 INTRODUCTION

In gait rehabilitation of patients with neurological diseases such as spinal cord injury, stroke, and traumatic brain injury, physical therapists often assist the patient leg movement by using a treadmill and a partial body-weight support system [1]. In Japan, the number of aged people is rapidly increasing [2]. Predictably, it is expected that elderly patients who need gait rehabilitation will increase, that the physical therapists' burdens will increase and that the time that can be allotted to gait rehabilitation of each patient will become insufficient. In order to relieve the therapists from manually moving the legs of the patients, rehabilitation robot suits are needed that can assist the patient leg movement [3], [4].

In the design of rehabilitation robot suits, safety consideration for patients is one of the most important issues. Computer-aided control techniques can improve the safety of the robot suits [5], [6]. However, the computer may break down, which makes the software-based safety measure inadequate. Therefore, a robot suit with hardware-based safety devices would be desirable to guarantee safety even under breaking down of the computer.

Emergency switches and joint limiters are often used as hardware-based safety devices [7], [8]. When the computer does not work, emergency switches are useful for stopping the robot suits. Also, joint limiters can prevent the hyperextension of the patient's joints. However, the patient and/or the physical therapists may not be able to push the emergency switch in case of emergency. Joint limiters involve risks such as (1)the robot suit may move the patient's leg at an unexpected high velocity and (2) the robot suit may provide an unexpected high torque to the patient's joint, before the patient's joint is stopped by the joint limiter, as mentioned in section 2.

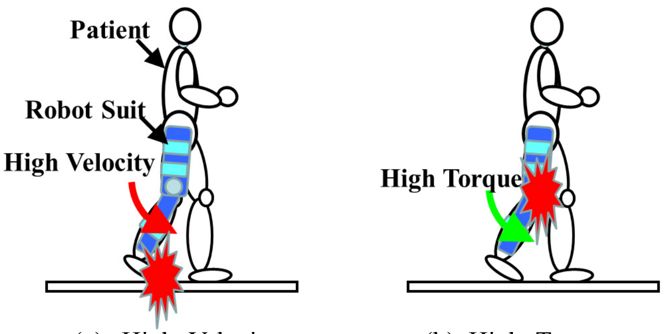
In this paper, we present a new rehabilitation robot suit with two hardware-based safety devices – "velocity-based safety device" and "torque-based safety device". The robot suit assists a patient's knee joint. The safety devices consist of only mechanical components without actuators, controllers, or batteries. The velocity-based safety device can switch off the motor of the robot suit if the device detects an unexpected joint angular velocity. Also, the torque-based safety device can switch off the motor if the device detects an unexpected joint torque. The safety devices can work even if the computer does not work.

This paper is organized as follows. In section 2, we briefly describe the safety problems in rehabilitation robot suits and two hardware-based safety devices. In section 3, we explain the basic structure and mechanism of the rehabilitation robot suit with two hardware-based safety devices. Section 4 concludes this paper.

2 REHABILITATION ROBOT SUIT WITH HARDWARE-BASED SAFETY DEVICES

We consider a rehabilitation robot suit which assists a patient's knee joint. The robot suit is controlled by a computer.

Assume that the computer of the robot suit breaks down. If an unexpected high velocity of the motor occurs, the patient's foot may collide with the ground at high speed as shown in Fig.1(a). If the motor generates an unexpected high torque, the patient may feel pain as shown in Fig.1(b). Therefore, we present a rehabilitation robot suit equipped with two safety devices (velocity-based safety device and torque-based safety device).



(a) High Velocity (b) High Torque

Fig. 1. Problems in computer failure

The characteristics of the velocity-based safety device are as follows:

(1) If the angular velocity of the motor exceeds a preset threshold level, then the safety device can switch off the motor. We call the preset threshold level the "detection velocity level".

(2) The detection velocity level is adjustable.

By (1), we can expect that the velocity-based safety device prevents from moving the patient's leg at a high speed. Furthermore, by (2), we can adjust the detection velocity level according to the requirement of each patient's gait exercise.

Also, the characteristics of the torque-based safety device are as follows:

(3) If the torque which the robot suit provides to patient's knee exceeds a preset threshold level, then the safety device can switch off the motor. We call the preset threshold level the "detection torque level".

(4) The detection torque level is adjustable.

By (3), we can expect that the torque-based safety device prevents from providing an unexpected high torque to the patient. Furthermore, by (4), we can adjust the detection torque level according to the requirement of each patient's gait exercise.

3 BASIC STRUCTURE & MECHANISM

3.1. Basic Structure

Fig.2 shows the rehabilitation robot suit with the velocity-based safety device and the torque-based safety device. The robot suit is worn on a patient's leg by two thigh braces and a calf brace.

Fig.3 shows the basic structure. A motor is mounted on *Frame A*. The motor torque is transmitted to *Calf Brace* via *Worm Gear*, *Worm Wheel*, *Shaft A*, *Plate A*, *Torsion Spring*, *Gear C, Gear D*, *Shaft B*, and *Frame B*. The velocity-based safety device consists of *Gear A*, *Rotary Dumper*, *Bar*, two *Springs*, two *Pins*, and two *Switches*.

Fig.4 shows the details of velocity-based safety device. *Gear A* is attached to *Shaft A*. *Gear B* meshes with *Gear A*. *Rotary Dumper* is connected to *Gear B*. Bar is connected to the axis of *Rotary Dumper. Bar* is also attached to two *Springs*. The ends of the *Springs* are connected to *Frame A* by two *Pins*.

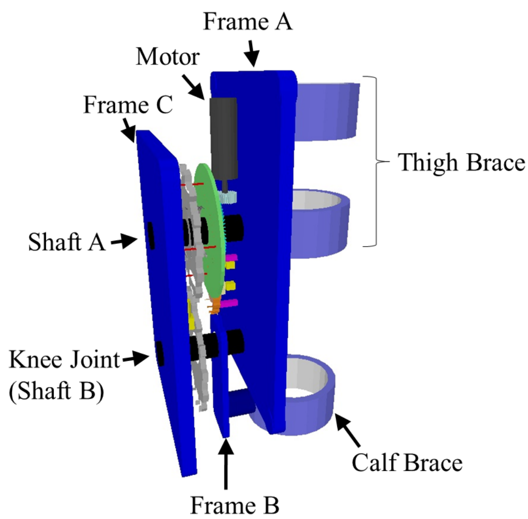


Fig. 2. The rehabilitation robot suit with safety devices

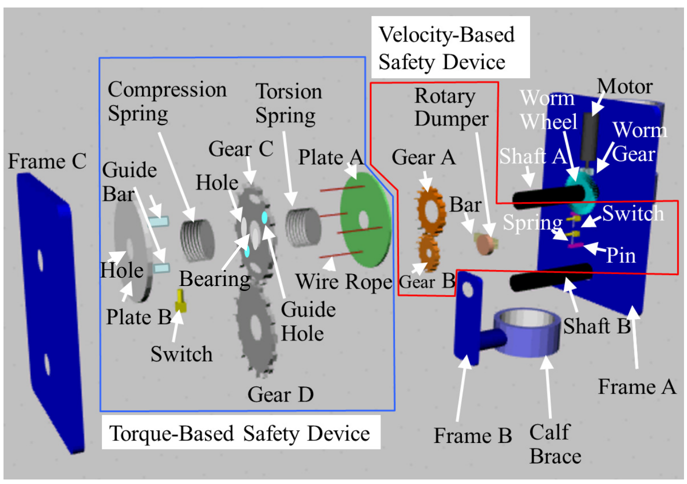


Fig. 3. The basic structure

Next, we explain the structure of torque-based safety device by using Fig.3. *Plate A* is attached to *Shaft A*. The *Torsion Spring* is directly installed between *Plate A* and *Gear C*. Four *Wire Ropes* are connected to *Plate A* and *Plate B* through 4 *Holes* of *Gear C*. *Gear C* is attached to *Shaft A* via *Bearing*. *Compression Spring* is installed between *Plate B* and *Gear C*. *Shaft A* is inserted to *Hole* of *Plate B*. Two *Guide Bars* attached to *Plate B* are inserted to two *Guide Holes* of *Gear C*. By the geometric restriction, *Plate B* and *Gear C* can rotate around *Shaft A* together, and *Plate B* can slide along *Shaft A* when *Plate B* is pulled by four *Wire Ropes*.

3.2. Mechanism

(1) Velocity-based Safety Device

Fig.5 shows the mechanism which mechanically detects the unexpected robot suit motion on the basis of the angular velocity of the motor. The damping torque by *Rotary Damper* and the spring torque by *Springs* act on *Bar*, when *Gear B* is rotated by the motor. As the motor velocity increases, the damping torque increases. If the motor velocity exceeds the detection velocity level, *Bar* rotates by the torque difference between the damping torque and the spring torque and switches off the motor. Also in the opposite direction, *Bar* can switch off, as shown in Fig.6. The detection velocity level is adjustable by changing the attachment positions of *Springs* as shown in Fig.7.

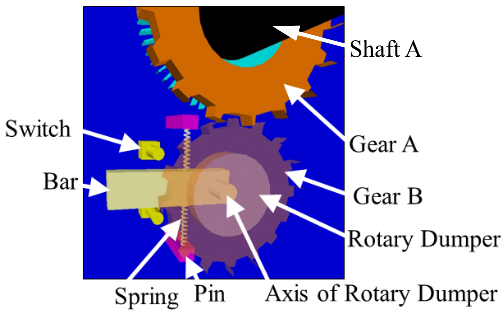


Fig. 4. The velocity-based safety device

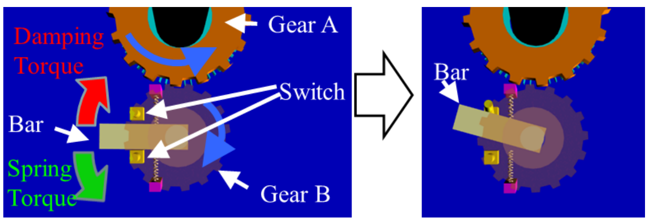


Fig. 5. The switch-off mechanism in the velocity-based safety device

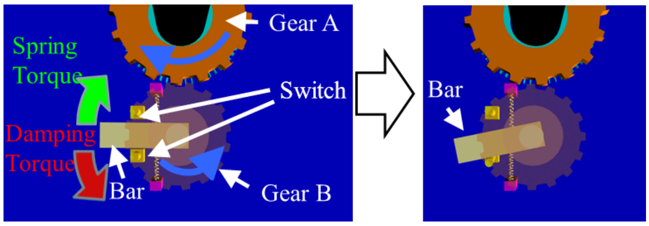


Fig. 6. The switch-off mechanism in the velocity-based safety device (in the opposite direction)

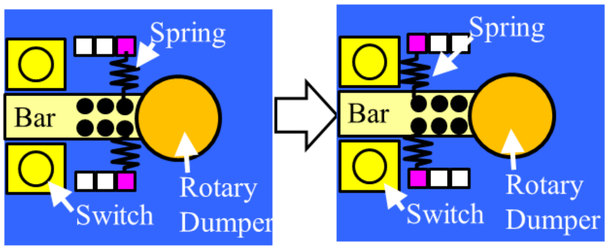


Fig. 7. Setting of the detection velocity level

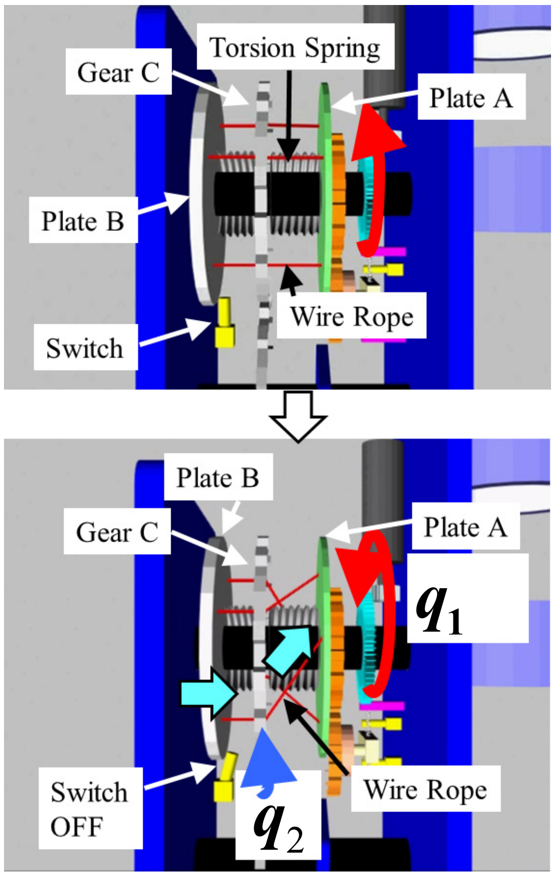


Fig. 8. The switch-off mechanism in the torque-based safety device

(2) Torque-based Safety Device

Fig.8 shows the mechanism which mechanically detects the unexpected robot suit motion on the basis of the torque which the robot suit provides to patient's knee. When the torque acts on *Torsion Spring*, the angle difference (q_1-q_2) between *Plate A* and *Gear C* generates (q_1: the angle of *Plate A*, q_2: the angle of *Gear C*) and *Plate B* is pulled by four *Wire Ropes*. If the torque exceeds the detection torque level, *Plate B* switches off the motor. Also in the opposite direction, *Plate B* can switch off as shown in Fig.9. The detection torque level is adjustable by changing the attachment position of *Switch* as shown in Fig.10.

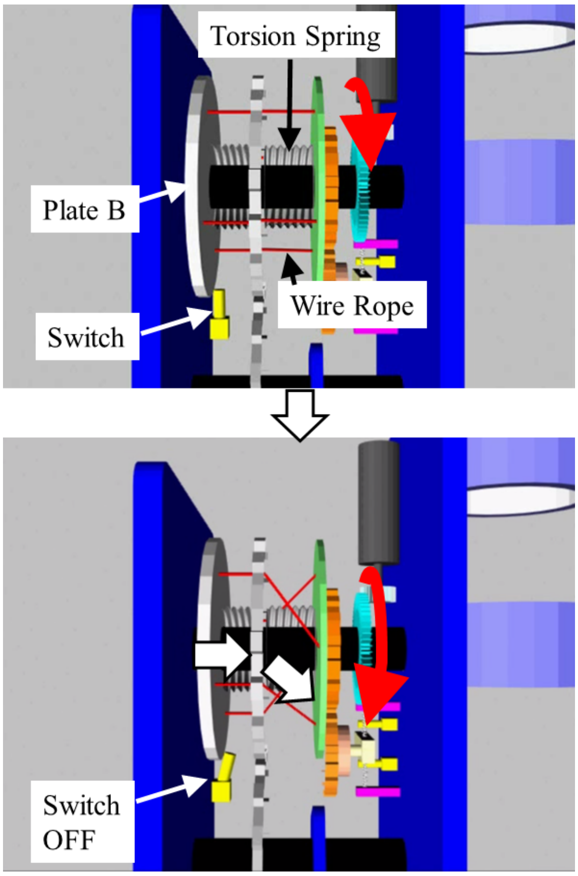


Fig. 9. The switch-off mechanism in the torque-based safety device (in the opposite direction)

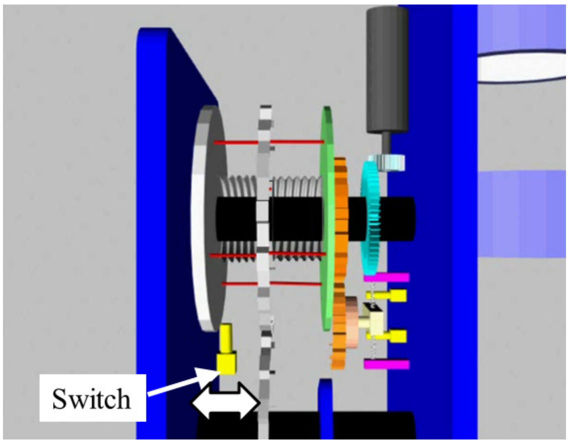


Fig. 10. Setting of the detection torque level

4 CONCLUSION

We presented a new rehabilitation robot suit with two hardware-based safety devices (velocity-based safety device and torque-based safety device). In the future, we will build the robot suit and experimentally examine the usefulness of the two hardware-based safety devices.

ACKNOWLEDGMENT

This work was supported by Overseas Research Visit Program of Tokai University (2012).

REFERENCES

[1] Kelly P Westlake1 and Carolynn Patten (2009), Pilot study of Lokomat versus manual-assisted treadmill training for locomotor recovery post-stroke, Journal of NeuroEngineering and Rehabilitation 2009, 6:18.

[2] Cabinet Office, Government of Japan (2011), Annual Report on the Aging Society: 2010 (Summary), Cabinet Office Japan, 2011, pp.2-5.

[3]Robert Riener (2012), Technology of the Robotic Gait Orthosis Lokomat, Neurorehabilitation Technology, 2012, pp.221-232.

[4]Kenta Suzuki, Gouji Mito, Hiroaki Kawamoto, Yasuhisa Hasegawa, Yoshiyuki Sankai (2010),"Intention-Based Walking Support for Paraplegia Patient with Robot Suit HAL", Climbing and Walking Robots, 2010, pp.383-408.

[5] Kong K, Bae J, Tomizuka M (2012), A Compact Rotary Series Elastic Actuator for Human Assistive Systems, IEEE/ASME TRANSACTIONS ON MECHATRONICS, VOL. 17, NO. 2, 2012, pp.288-297.

[6] Bae J, Kong K, and Tomizuka M (2011), Control Algorithms for Prevention of Impacts in Rehabilitation Systems, 2011 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM2011), pp.128-133.

[7] Kawamoto H., Lee S., Kanbe S., Sankai Y., "Power Assist Method for HAL-3 using EMG-based Feedback Controller", Proc. of Int'l Conf. onSystems, Man and Cybernetics (SMC2003), 2003, pp.1648-1653.

[8] Feng Chen, Yong Yu, Yunjian Ge, Jian Sun and Xiaohong Deng, A PAWL for Enhancing Strength and Endurance during Walking Using Interaction Force and Dynamical Information", Climbing and Walking Robots: towards New Applications, 2007, pp.417-428.