Study on Development of Active-Passive Rehabilitation System for Upper Limbs: Hybrid-PLEMO

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Abstract. In recent years, many researchers have studied the potential of using robotics technology to assist and quantify the motor functions for neuron-rehabilitation. Some kinds of haptic devices have been developed and evaluated its efficiency with clinical tests, for example, upper limb training for patients with spasticity after stroke. Active-type (motor-driven) haptic devices can realize a lot of varieties of haptics. But they basically require high-cost safety system. On the other hand, passive-type (brake-based) haptic devices have inherent safety. However, the passive robot system has strong limitation on varieties of haptics. There are not sufficient evidences to clarify how the passive/active haptics effect to the rehabilitation of motor skills. In this paper, we developed an active-passive-switchable rehabilitation system with ER clutch/brake device named “Hybrid-PLEMO” in order to address these problems. In this paper, basic structures and haptic control methods of the Hybrid-PLEMO are described.

1. Introduction

The increasing numbers of the aged people and their physical deteriorations have become one of the most serious problems in many countries. Many stroke patients suffer from disabilities which restrict Activities of Daily Living (ADL), e.g., reaching actions. Therefore, sufficient rehabilitative training is necessary for such patients. Nowadays, Evidence Based Medicine (EBM) is required strongly in the field of rehabilitation. Therefore, rehabilitation systems that utilize robotics technologies are expected for; 1) quantification of the effect of the rehabilitative training; 2) enhancement of the motivation for patients with creating new training methods (many patients are giving up rehabilitative training because of its boredom); 3) improvement of the efficiency of physical therapist’s works.

Krebs H.I., et al. [1] have developed active (motor-driven) haptic device (MIT-MANUS) and conducted many clinical tests for upper limbs rehabilitation. However, the motor-driven robots basically require high-cost safety system compared to passive (brake-based) devices. Book W.J., et al. [2] have developed passive haptic devices. In their system, conventional powder brakes were used as haptic generators. Generally, the response time of the powder brake is more than 100ms and it causes lack in quality of force feedback.

To solve these problems, we have developed two-types (active-type [3] and passive-type [4]) of rehabilitation system for upper limbs with ER fluid (Electrorheological fluid) actuators / brakes [3]. Due to the rapid response of ER fluids, our haptic device presented good performance as a force display. ER fluid actuator-type system has high safety and good performance for haptic control [3], but it needs a lot of cost and size for actuator. On the other hand, ER fluid brake-type system is very...
compact and inherently safe; however, it has strong limitation of haptic varieties. At present, we do not have guidelines to determine which type is suitable for an individual case, because there are not sufficient evidences to clarify how the passive/active haptics effect to rehabilitative trainings for motor skills. In this study, we have developed an active/passive switchable rehabilitation system with ER clutch/brake device named “Hybrid-PLEMO” (see Fig.1) in order to address these problems in common environment. In this paper, basic structures and haptic control methods of the Hybrid-PLEMO are described.

2. ER fluid Device for Active / passive switchable mechanism

2.1. Mechanism

ER fluid is one of the functional fluids of which rheological properties can be changed by applying electrical fields [5]. In this paper, particle-dispersed-type ER fluid is used.

Figure 2 shows a basic structure of the ER-fluid-clutch-type actuator (or simply, ER Actuator). As mentioned in the previous report [3], this actuator is safer than other conventional actuators. In this paper, we utilized this actuator as a torque generator. Additionally, by fixing its input rotation, we can switch it as a brake system. In this study, we adopted this actuator (active) / brake (passive) switchable system.

2.2. ER fluid clutch / brake device with double shafts

Figures 3 show a developed ER fluid clutch / brake device (or simply, ER device in this paper). This device has two controllable shafts with a double-shaft structure. An inner shaft and an outer shaft are connected to the multi-layered disks (output disks) for each. Each disk is laminated with case-side disks (input disks) in alternative shift with 1mm gap. The ER fluid is filled in the gap. When the casing is rotated with

![Table](image)

| TABLE 1. SPECIFICATIONS OF HYBRID-PLEMO |
|------------------------------------------|
| Size | W0.6m*D0.5m*H1.0m |
| Motion region | W0.6m*D0.5m |
| Adjustable angle of the inclination is | -30 ~ 90deg |
| Maximum force | 4kgf at end effector |
| Num. of 2 DOF ER clutch | 2 |
| Motor | 40W |

![Figure1](image)

![Figure2](image)

![Figure3](image)

![Figure4](image)
motors, input disks are rotated simultaneously and the device works as a clutch. On the other hand, when the casing is fixed, the device works as a brake.

Diameter and height of this device are 192mm, 225mm, respectively. Diameter, thickness and gap of disks are 155mm, 1.0mm, 1.0mm, respectively. Numbers of disks are 4 for each group. Figure 4 shows output torque of this device.

3. Hybrid-PLEMO

3.1. Concept

The Hybrid PLEMO has 2 controllable DOF on a working table and 1 uncontrollable DOF of the inclination of the working table (see Fig.1). We defined this working space as a “Quasi-3-DOF Workings pace”. An operator grasps a handle on the end-effector of its arm, watches visual information on a display and plays application software as rehabilitative training and evaluation test.

In previous report [4], we used only ER brake for its torque control. Therefore, it was a passive haptic device. In Hybrid PLEMO, we used the active/passive switchable device mentioned above with the same Quasi-3-DOF mechanism. Table 1 shows specifications of the Hybrid-PLEMO.

3.2. Force Control Mechanism

Haptic force on the end-effector of Hybrid PLEMO is controlled with torque control unit including ER devises mentioned above. Figure 5 shows the torque control unit for the Hybrid-PLEMO system. In this structure, a “motor” (AC servomotor) rotates slowly and generate two directional rotations (clockwise; CW and counter-clockwise; CCW) with “gears”. These rotations are transmitted to two ER devices. Therefore, “ER device 1” controls torques of CW direction. At the same time, “ER device 2” controls torques of CCW direction.

Figure 6 shows a parallel linkage mechanism for the end-effector of the Hybrid-PLEMO. Inner shafts of two ER devices are connected with “Sub Link1” and it controls torques of “Link2”. In the same manner, outer shafts of two ER devices are also connected with “Sub Link2” and it controls torques of “Link1”. Finally, we can control haptic forces on the handle with the parallel linkage that consist of “Link1” and “Link2”.

3.3. Control System

Figure 7 shows control system for the Hybrid PLEMO. Absolute encoders (FA Coder, TS566N320, Tamagawa Seiki Inc., Japan, resolution: 17bits) measure the rotational angle of each link. We can calculate the position and the velocity of the handle depending on each angle. Digital Input/Output (DIO) board (PCI-2154C, Interface Inc., Japan) loads this information to a controller (personal computer). Operating handle includes a force sensor (OPFT-220N, Minebea Co. Ltd., Japan), and operating force is measured by this sensor. A potentiometer (CP-2F, Midori Precision Inc., Japan) measures the inclination of the worktable and the angle is loaded by Analog/Digital (A/D) converter board (PCI-3165, Interface Inc., Japan, resolution: 16bits). The torque of the ER devices is controlled...
amplifiers (High voltage amplifier, MAX-ELECTRONICS, Co. Ltd., Japan). Digital/Analog (D/A) converter board (PCI-3338, Interface Inc., Japan, resolution: 12bits) outputs the reference signal to the amplifiers.

A controller is a personal computer (DOS/V), and an operating system (OS) is Vine Linux 3.2 and ART-Linux (kernel 2.4.31) as a real-time OS. Open-GL and Glut3.7 are used for the graphic library. Graphic process and control process are executed by one PC. Multi-process programming is used to realize it. The control process is repeated by 1 [ms] exactly.

3.4. Experimental result for constant resistive force

To evaluate the performance of the haptic force of the Hybrid-PLEMO, constant resistive forces with active / passive haptic control were measured. Figure 8 shows experimental results. A solid line represents force with the active haptic control, and a dashed line represents force with the passive haptic control. In these experiments, an operator manipulated a handle forward from initial position. Initially, resistive force was zero, but when the hand entered a friction area, resistive force of constant 5 N instantly presented. As shown in this figure, haptic forces with both of active/passive haptic methods were accurately controlled.

4. Conclusion

This paper described the development and evaluation of “Hybrid PLEMO”, which is one of the rehabilitation systems for upper limbs with quasi-3DOF mechanism and switchable mechanism of active/passive haptic controls. We expect to use this system to clarify the effects and roles of active / passive force feedback in rehabilitative training.

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