Hand Rehabilitation Support System Based on Self-Motion-Control

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***Abstract*—This paper presents a hand rehabilitation support system for self-performing rehabilitation therapies. The developed system consists of hand exoskeleton device, which provides individual finger joint motion for disabled persons, and a lateral symmetric master-slave motion assistant system joined with virtual reality (VR) environment. Most of disability caused by CVA (Cerebral Vascular Accident) or bone fracture are hemiplegia where impaired hand is only in one side. Based on the peculiarity of this disability, we adopted a symmetric master-slave motion assistant system in which the impaired hand is driven by the healthy hand in the opposite side.**

***Keywords*—Rehabilitation, Hand, Master-Slave, VR**

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I. INTRODUCTION

The number of patients who had a function disability of certain part of the body caused by CVA (Cerebral Vascular Accident) or bone fracture is increasing in resent years as shown in Fig.1. In order to back to normal daily life, these patients need timely and persistent rehabilitation to recover the function ability of that part of the body. Since the number of therapists is not enough for patients (e.g., the number of physical therapists and occupational therapists in Japan are 21 thousand and 10 thousand, respectively), it is not easy for the patient to have long rehabilitation training supported by therapist. A solution of this issue would be to provide a self-performing rehabilitation system that supports the patient to perform the rehabilitation exercise by his/her self.

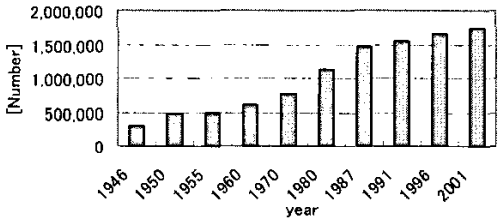

Fig. 1. Number of orthopedically impaired persons in Japan

This paper presents a virtual reality enhanced hand rehabilitation support system with symmetric master-slave motion assistance. In the developed system, individual finger joint motion of impaired hand is supported to move by an exoskeleton device that is controlled by the finger joint motion of the patient's healthy hand. A concept of the proposed rehabilitation system, design of the exoskeleton device, VR environment and evaluation result of the developed system by therapists are presented.

II. FINGER MOTION ASSISTANT DEVICE

During hand rehabilitation session, therapists extend and flex each finger joint of the impaired hand of the patient independently within its movable area for many times. The device that can assist such independent finger motions is required. From that perspective, we have developed an exoskeleton device which supports motions of flexion/ extension of metacarpophalangeal (MP) joint, flexion/ extension of proximal interphalangeal (PIP) joint, and adduction/abduction of finger.

In addition to the independent finger motion assistant, we take account of the following three requests during the design of the device:

- Flexibility for several sizes of patient's hand
- Safety
- Easy attachment

To get several hand sizes flexibility, an exoskeleton device whose configuration is a closed loop link consisting of mechanical link and human finger as shown in Fig.2 is adopted. Two joints whose angles are denoted by θ_1 and θ_5 are active, while the others are passive. Although it is not shown in the figure, active joint is prepared for the adduction/abduction. Therefore, three actuators are required to drive this device. DC motors are selected as the actuators because they are compact and easily controlled. For safety issue, the power of the actuators is carefully designed so that the device does not injure the patients. For easy attachment, Velcro straps are utilized for fixing the fingers to the motion assistant device.

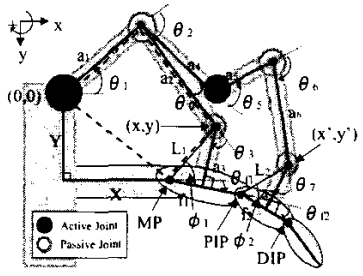

Fig. 2. Exoskeleton Device model

The prototype exoskeleton device is shown in Fig.3. This device assists the flexion/extension for the MP and PIP joints, and adduction/abduction of the MP joint. This device contains the asymmetric differential gears developed in our laboratory for anthropomorphic robot

hand [1]. These gears make the device compact while keeping the two rotation-axis, i.e., flexion/extension and abduction/adduction, orthogonal.

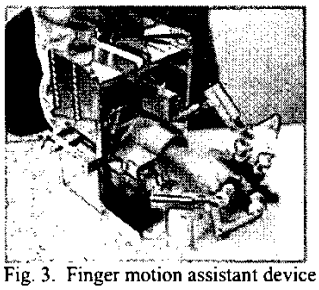

Fig. 3. Finger motion assistant device

III. Symmetric Master-Slave Control

A. Concepts

Most of disability caused by CVA (Cerebral Vascular Accident) or bone fracture are hemiplegia and impaired hand is only in one side. Based on the peculiarity of this disability, we propose lateral-symmetric master-slave control for the motion assistant device; the healthy patients' hand produces the reference motion for the exercise as the master system, while the slave system, i.e., the motion assistant device that attached to the impaired hand, reproduces the motions that enables the impaired hand to make the reference motions symmetrically, as shown in Fig.4.

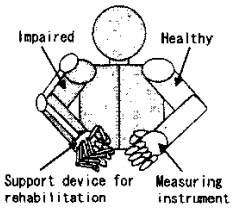

Fig. 4. Symmetric master-slave system

B. System Architecture

The system architecture is shown in Fig.5. The motion of the healthy hand in master side is measured by using the data glove which detects 22 joint angles and transferred them to the control computer. From the measurement data of joint angles of the healthy hand, the inverse kinematics is solved to obtain the reference joint angles of the motion assistant device in slave side, which realize the symmetric finger motion of the impaired hand. The motion assistant device is controlled by PD control method.

IV. Exercise with Virtual Reality

Virtual reality (VR) simulation is utilized to incorporate amusement aspect to rehabilitation system. This could prevent patients from getting bored during painful exercise. The VR environments are constructed on the computer display using OpenGL. As an example, Fig.6 shows a snapshot of the virtual environment during pinching training session.

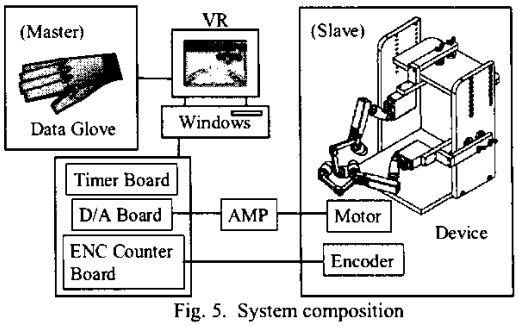

Fig. 5. System composition

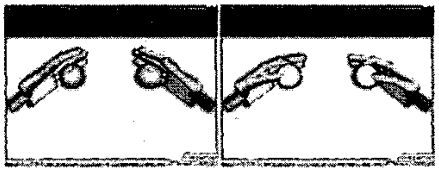

Fig. 6. Computer graphics at pinching training

V. System Evaluation

Two occupational therapists evaluated whether this device possesses enough performance for actual rehabilitation exercise. As a result of their actual trials, they concluded that this device would be helpful for stroke patients in the flaccidity period. They also commented, that the force for assisting motion is a little bit small.

VI. Business Model

We forecast that most of rehabilitation institutes in Japan need the proposed rehabilitation support system to correspond to the increasing number of disabled persons.

VII. Conclusion

A virtual reality enhanced hand rehabilitation support system with symmetric master-slave motion assistant has been presented for self-performing rehabilitation therapies. The evaluation by therapists has shown that the developed rehabilitation system has a high potential for self-performing rehabilitation therapy for hand disabled persons with hemiplegia. We are planning to evaluate the recovery effect of this system by conducting a clinical test on patients.

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