Chapter 43
Design and Control of a Hand–Assist Robot with Multiple Degrees of Freedom for Rehabilitation Therapy

Haruhisa Kawasaki
Gifu University, Japan

Satoshi Ueki
Toyota National Colleges of Technology, Japan

Satoshi Ito
Gifu University, Japan

Tetsuya Mouri
Gifu University, Japan

ABSTRACT

This chapter focuses on a patient self-controlled rehabilitation system using our developed exoskeleton-type hand-motion-assist robot and tele-rehabilitation. The virtual reality-enhanced new hand rehabilitation support system, which we have developed for stroke patients in the acute stage, is aiming to allow such patients to conduct every day exercises by themselves without supervisors. This system features a multi-DOF motion assistance device, a virtual reality interface for patients, and a symmetrical master-slave motion assistance training strategy called "self-motion control", in which the stroke patients' healthy hand on the master side creates the assistance motion for the impaired hand on the slave side. Moreover, a tele-rehabilitation system consisting of a hand rehabilitation support system for the patients, an anthropomorphic robot hand for the therapist, and a remote monitoring system for diagnosing the degree of recovery is explained.

1. INTRODUCTION

A stroke occurs when the blood supply to the brain is blocked or a blood vessel in the brain bursts. The loss of blood to the brain means a loss of oxygen, which then injures or kills brain cells. Fifteen million people worldwide suffer a stroke every year. Nearly 6 million die, and another 5 million are left permanently disabled (www.world-heart-federation.org, n.d.; www.who.int, 2002). Stroke is the second leading cause of disability, after dementia. Disability from stroke may include loss of vision and / or speech, paralysis and confusion. Globally, stroke is the second leading cause of death for those over 60 years of age, and the fifth leading cause of death in people aged 15–59. In many developed countries, the incidence of stroke is declining even though the actual number of strokes is increasing because of the ageing population. In the developing world, however, the incidence of stroke is increasing. In China, 1.3 million people have a stroke each year, and 75% live with varying degrees of disability as a result. The predictions for the next two decades suggest a tripling in stroke mortality in Latin America, the Middle East, and sub-Saharan Africa. In the USA, there are approximately 4 million people living with the effects of stroke (www.ninds.nih.gov, 2014). In addition, there are millions of husbands, wives, children and friends who care for stroke survivors and whose own lives are personally affected. In Japan, the number of patients with a disability as a result of a cerebral vascular accident (CVA) or bone fracture topped 1.3 million in 2008 (www.e-stat.go.jp, 2013).

Stroke patients require timely and persistent rehabilitation to recover lost abilities and regain their normal daily lives. Successful rehabilitation depends on the amount of damage to the brain, the skill of the rehabilitation team, cooperation of family and friends, and timing of rehabilitation. Rehabilitation training can be categorized into the following stages: acute, convalescence, and maintenance. It is understood that the earlier phases of rehabilitation contribute to the recovery of lost abilities and skills. In particular, the acute and convalescence stages can have a significant effect on preventing muscle atrophy. However, it is not always possible for patients to receive long rehabilitation sessions with therapists, who are in relatively short supply. A solution to this problem would be a rehabilitation support system that allowed patients to carry out rehabilitation exercises by themselves. We call this patient self-controlled rehabilitation therapy, and estimate that such systems will find a large market in an aging world.

Many systems for rehabilitation have been studied. Functional electrical stimulation (FES) (Heasmam et al., 2000; Thorsen, Spadone, & Ferrarin, 2001) has proven to be a valuable tool in the restoration of arm function, but is not suitable for patient self-controlled rehabilitation therapy. Many aspects of robotic arm rehabilitation therapy (Krebs, Hogan, Aisen, & Volpe, 1998; Carignan, Liszka, & Roderick 2005; Gupta & O'Malley, 2006; Reinkensmeyer, Pang, Nessler, & Painter, 2002), including clinical tests (Volosyak, Ivlev, & Graser, 2005; Kahn, Zygman, Rymer, & Reinkensmeyer, 2001; Mahoney, Machiel Van der Loos, Lum, & Burgar, 2003), have been reported. Similarly, lower limb rehabilitation therapy (Saint-Bauzel, Pasqui, & Monteil, 2009) has been reported with clinical results. Most disabilities caused by CVAs are hemiplegic; that is, only one side is affected. Arm rehabilitation therapy with the aid of a robot (Burger, Lum, Shor, & Machiel Van der Loos, 2000), which involves bimanual, mirror-image, patient-controlled therapeutic exercises, is one type of self-controlled rehabilitation.

On the other hand, hand rehabilitation is somewhat difficult because the hand possesses many degrees of freedom (DOF) of motion, and a hand motion-assist device must be small in size to be attached to the hand. Research on the function of the fingers by FES (Cameron, McDonald, Anderson, & Prochazka, 1999; Lauer, Kilgore, Peckham, Bhadra, & Keith, 1999), hand rehabilitation devices (Mulas, Folgheraiter, & Gini, 2005; Wege & Hommel, 2005; Sarakoglou, Tsagarakis, & Caldwell, 2004; Noritsugu, Yamamoto,

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