Rehabilitation Robotics: From Expensive Tools for Specialized Hospitals towards Home and Tele-Rehabilitation Use

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Abstract – ***Rehabilitation robotics has found acceptance in most of the top level national rehabilitation centers in Europe, United States and Canada, and in countries of the Far East. The main successes have been made in support or substitution of manual therapy for locomotion and reaching using stationary multi degree of freedom robotic systems. These systems present a technological complexity that requires constant maintenance and highly qualified operators. They are only affordable by big rehabilitation centers and clinics. On the other hand research results indicate that successful rehabilitation requires more involvement and time of the impaired subjects than the duration of their hospitalization. Outpatient treatments and the continuation of the therapy in local and smaller rehabilitation facilities or at home should follow the clinical rehabilitation. Current challenges are the implementation of affordable rehabilitation robotics for outpatient centers and the development of low cost solutions for domestic environments. This article presents contributions that use solutions necessary for lower cost rehabilitation robotic systems, i.e. low-cost compliant robotic systems, adapted gaming controllers, and new rehabilitation concepts using remote support and supervising. Important considerations for systems and approaches used in domestic and tele-rehabilitation, tele-rehabilitation software solutions, low cost training platforms, and workstations are presented and described.***

Keywords - ***Robotic rehabilitation, motor impairment, low-cost home rehabilitation systems, tele-rehabilitation.***

I. Introduction

Rehabilitation is a labor-intensive process involving a physical interaction between a patient and a therapist. Reducing the degree of permanent disability remains the goal of all rehabilitation programs as e.g. post stroke or SCI rehabilitation. Relying on the plasticity of the brain, new approaches to impairment reduction through managing sensorimotor treatment may contribute to a reduction in motor impairment [1]. While there is not one standard technique that occupational and physical therapists use for improving upper or lower extremity motor function, many of the techniques that are used require some manual assistance from the therapist to position, guide, and/or support all or some of the weight of the limb [2-4].

Previous studies have shown that patients who performed progressive resistance exercises with adequate motor control for as little as 3-4 times per week for 6-12 weeks improved both strength and functional activities [5]. Further-more, recently published research work confirms that better results in terms of rehabilitation outcome are obtained in specialized care centers where patients receive more therapy per day for extended periods of time [6]. However, mean lengths of hospitalization in Spain are on average only 10.2 days followed by less than half of a day in a stroke unit [7]. Similarly in the United States, Medicare coverage policies maintain the current median length of stay in inpatient rehabilitation facilities at only 16 days. In-home services are covered for only the next few weeks following discharge followed by treatments at an outpatient facility 2-3 times per week for a period of 1-3 months [8]. There is evidence that even in stable post-stroke conditions patients can undergo reduction of sensory-motor impairment if proper therapy is administered [9]. Robotic assisted rehabilitation has become a major focus in this research and for clinical assessment.

However, many of these robotic assisted rehabilitation methods are conducted with stationary, complex high-tech systems and can only be provided and afforded by leading rehabilitation centers. Smaller centers, outpatient facilities or regional hospital cannot afford many of these high end rehabilitation robots, which require technicians and often highly educated researchers to be operated and maintained. Thus, it is evident and necessary that simpler robotic systems, cheaper to maintain and easy to operate need to be developed and tested in its effectiveness. This demand has been recognized and following examples show that lower cost rehabilitation systems can be made.

II. REHABILITATION SYSTEMS SUITABLE FOR OUTPATIENT CLINICAL AND HOME USE

A. Gaming based motor-rehabilitation approaches

Gaming consoles associated with customized or adapted controllers have recently been used in rehabilitation of elderly people and disabled. As an example the *Nintendo Wii* console is installed in numerous therapeutic centers. It provides several controllers (Wii balance board, Wiimote combined with Pilates rubber bands, etc.) that invite active exercising in a motivating gaming like scheme using high scores and gradually increased difficulty levels. As much as actuation is concerned these controllers and a gaming environment can be augmented with haptic and robotic actuation. A selection of games reported and used in a rehabilitation environment have been analyzed and scored in [10]. *UniTherapy* [11] applied a fun therapy toolbox consisting of third-party games like Solitaire or Pac-Man together with conventional joysticks and force-feedback steering wheels to stroke therapy. The Joystick (*TheraJoy*) and steering wheel (*TheraDrive*) are customized such that they can be grasped by subjects with impaired arm and hand function. Results in a controlled study supported the potential benefit of robot and computer assisted motivating therapy [11].

B. Low-cost lower extremity motor- rehabilitation systems

1) Balance trainers

A device called *Balance Trainer* has been developed by Z. Matjacic and colleagues at University of Aalborg. The device has two springs that provide an adjustable support in sagittal and coronal planes during standing. In more sophisticated version the vertical support rods are actively driven. Combined with a low-cost COP measurement platform [12], e.g. the Wii balance board and a gaming or virtual reality environment people with balance problems can train standing stability.

2) Gait trainers

A new category of gait trainers are robotic systems, similar to walkers, that allow ground level walking and provide passive or actuated balance control. An example in the low-cost range of this category is the *Walkaround* [13]. It provides to the user sufficient stability such that a rehabilitation training can be easily provided by one physiotherapist and the user, e.g. a stroke subject can learn to overcome a static walking with double stance phase and relearn a dynamic walking in a safe manner. A preliminary study has shown that the Walkaround could increase walking speed in acute stroke patients significantly [13].

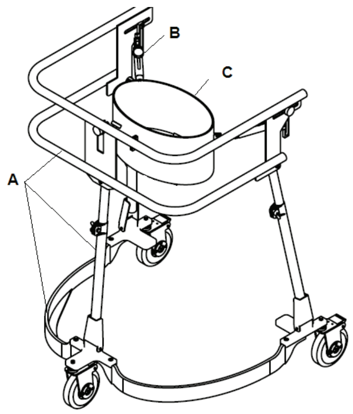

Figure 1: Walkaround stability trainer

C. Low-cost upper extremity motor-rehabilitation systems

1) Hand rehabilitation

The *Novint Falcon* is a low-cost haptic gaming interface. Combining the Falcon with a parallel kinematic construction a fine motor rehabilitation system called *MyScrivener* has been developed. An early prototype showed dramatic visible improvements in handwriting of ADHD children.

The *Hand Mentor* is an exoskeleton hand rehabilitation system for *Active Repetitive Motion* ™. It provides controlled resistive force to the hand and wrist. As actuator the system uses a compliant air muscle actuator. Biofeedback is provided by incorporated EMG electrodes. The system is reported to be well accepted by the patients and has been assessed to work in a clinical setting [14].

2) Arm rehabilitation

There are numerous workstation-like systems for arm rehabilitation. For example, the *Rehaslide Duo* is a commercially available desk exercising system. It provides resistance to the movement but no active biofeedback. The hand rest can be adjusted in different angles.

A system that provides low-cost planar arm movement training is called *Armassist*. It measured the lifting force and position and orientation of the arm while the subject performs dual lifting and reaching out tasks. The wheels of the table robot can be passive or actuated in order to guide the arm on the table. The system is wirelessly connected to a personal computer and a number of training, gaming and entertainment tasks can be performed.

HapticDrive is a low cost 2-DOF active compliant robot for planar arm movements, wrist movements, and reaching movements. It allows with a simple locking mechanism to select the type of movements. A spring/cable driven actuation principle provides patient safety and a low-cost actuation. First, preliminary results showed great improvements in pro/supination movements in chronic stroke subjects that trained for 10 sessions over three weeks.

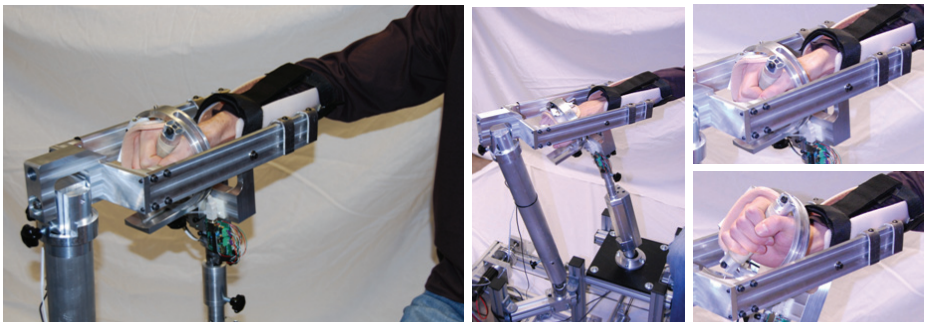

Figure 2: HapticDrive device prototype for arm and wrist training

III. TELEREHABILITATION

Telerehabilitation according to Jack Winters [15] can be divided in Teleconsultation, Telemonitoring, Telehomecare, and Teletherapy. Teleconsultation is a standard face-to-face consultation using videoconferencing. Telemonitoring is a clinical application of measuring medical signals and sending the data to a center. Telehomecare is advising and learning ADL tasks over distance using videoconferencing or other means. Teletherapy is conducting therapeutic activities in a home setting using a therapy protocol. When these four telerehabilitation activities are plotted in a two-dimensional plot with intensity and duration as axes then it is clear that teletherapy is the high intensity long duration application [16]. As such it is important that this Tele activity needs to be provided in a cost efficient manner. If not then Telerehabilitation cannot be a solution for the ageing society as it will be too expensive. There are two feasible ways of cost-efficient telerehabilitation: Group therapy and community therapy. Group therapy is a therapy using either videoconferencing or virtual reality together with a closed group at scheduled times, whereas community therapy is a virtual reality therapy in a community space. Currently these concepts are not frequently used for therapy but they are widely applied in gaming and social communities.

In 1998, the US National Institute on Disability and Rehabilitation Research (NIDRR) initiated and established a National center of research for telerehabilitation [17]. NIDRR recognized the potential benefits of telerehabilitation in primary and secondary prevention for people with disabilities.

IV. Future direction

The trend towards simpler rehabilitation robots that can be applied in outpatient facilities or at home will continue. Telerehabilitation will be needed to facilitate quality service and day-by-day support when needed. It will provide means to increase efficiency in the ageing society. However, to be cost-effective some of the therapist guidance has to come by the rehabilitation robot itself, either by a consequent comprehensive design or by added intelligence. The system at home has to suggest the right grade of difficulty, help in comparing the outcome and guide the user with natural intelligence. it also has to carefully monitor the user, correct wrong posture, motivate or slow down the operator. From a technical point of view lots of artificial cognitive skills need to be added such that a tele-rehabilitation scenario will provide more that the saving of travel expenses of the customer to clinic.

A consequence the design of group and community therapy will help at first hand to provide efficient direction of many users by few therapists. Self-learning and see and copy strategies can be performed in such a community setup.

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