Design and Testing of Two Mechatronics Systems for Robotized Neurorehabilitation

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Abstract: This paper illustrates the design and the testing of two mechatronics prototypes useful for robotized neurorehabilitation and for motor training assessment. The two machines are called Bra.Di.P.O. (Brain Discovery Pneumatic Orthosis) and P.I.G.R.O. (Pneumatic Interactive Gait Rehabilitation Orthosis). They are electro-pneumatically controlled. This allows to obtain a lot of advantages: pneumatic systems give comfortable interaction between machine and patient; they are safe, clear and easy to connect to hospital plant; they are MR-compatible. These prototypes have been tested both in laboratory and at hospital and results obtained are good.

Keywords: medical pneumatic devices, fMRI analysis devices, pneumatic active exoskeletons, neurorehabilitation robots, mechatronics devices for lower limbs rehabilitation.

1. INTRODUCTION

The ability to walk is the basic factor for quality of life and for participation in social life. However, in normal life it is frequently affected by neurological diseases –spinal cord injury, stroke and traumatic brain injury, Kulig et al. (2008), Perry (1992), Sawicki et al. (2005). For the treatment in this area, gait training robot has played an important role. The recovery has to be simulated by training that aims at the function to be regained –train walking by walking. However, during a phase right after an incident, the control of the muscles is usually severely reduced.

Since 1980, the traditional approach is to suspend the patient over a treadmill with a harness and counter weights to help the patient to reduce body weight and to guide the patient's leg by two physical therapists.

Early gait rehabilitation training machine uses suspending system, treadmill to help patients with the treatment. However, this kind of process still needs the help of professional therapist during the training, so it could not be called as a robot but just a half automatic rehabilitation machine.

In 2000, *Freie University Berlin* invented successfully a kind of mechanical training device, Beyl et al. (2008), Barbeau et al. (2003), Yang et al. (2008). This rehabilitation device can repeat and correct the gait training of the patients, releasing the therapists from the heavy assistant training so that they can concentrate on the rehabilitation of patients with data analysis, Colombo et al. (2000), Jezernik et al. (2003), Hesse et al. (2000), Ferris et al. (2005).

Nowadays, Beyl et al. (2008), Gassert et al. (2008), Moser et al. (2003), Yu et al. (2007), Yu et al. (2008), an advanced technology of robots for the rehabilitation project has been carried on, combing the medical rehabilitation techniques and the automatic control process, such as Lokomat, Colombo et al. (2000).

The robot can simulate the regular pattern of normal walking gait movement. It can lead the movement of the lower limb, such to realize the dynamic training of almost every lower limb joint. It is also able to correct gait pattern of the hemiplegic patients, collecting data in order to achieve further gait analysis. It could offer a good treatment to the acute stroke or chronic lower limb motor dysfunction thus provides a possibility of a deep understanding of the law of central nervous rehabilitation.

From human gait analysis, we can easily analogize that a human gait training machine should have these factors: mechanical properties and power; adjustability; control of balance; auxiliary control.

Since 2006, the Department of Mechanics of Politecnico di Torino started the design, the construction and the experimentation of two innovative active pneumatic orthosis. They are called Bra.Di.P.O. (Brain Discovery Pneumatic Orthosis) and P.I.G.R.O. (Pneumatic Interactive Gait Rehabilitation Orthosis), Belforte et al. (2009), Belforte et al. (2011).

2. PROTOTYPES DESCRIPTION

Bra.Di.P.O. (figure 1a and b) is a mechatronic device with one DoF (Degrees of Freedom), useful to investigate the motor cortex behaviour with fMRI analysis, during the active or passive movement of patient feet. Movement is produced by means of two pedals (1) and (2) connected through bar (3) to a pneumatic cylinder (4). A series of holes (5) with a spin inside (6), allows to establish manually the endstroke of the actuator. The angle of pedals rotation is measured by means of an optical encoder (7). The structure (8) is useful to sustain patient's legs too.

In this case, a pneumatic control system was selected for three main reasons. First, it is compatible with the environment of the resonance chamber, where it is not possible to use electric/electronic controls or components which could be damaged by or interfere with the magnetic field and jeopardize the test. Second, it makes it possible to modulate the force on the foot by regulating operating pressure. Third, pneumatic control is clean, and thus suitable for hospital environments, where compressed air is available directly from the mains. All the materials used are MR-compatible.

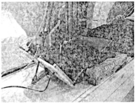

Fig. 1a. Bra.Di.P.O. in the scanner

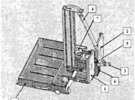

Fig. 1b. Bra.Di.P.O. schema

P.I.G.R.O., instead, is a new machine with six DoF (figure 2a and b), based on characteristics of universality, wearability and safety. In fact, it is a modular exoskeleton with anthropometric regulations from 10% percentile female to 95% percentile male. Furthermore, it is an active exoskeleton, controlled by five pneumatic actuators for each leg (two for hip; two for knee; one for ankle). The movement is possible only in the sagittal plane, but some little movements in the frontal plane are also allowed by the flexibility of construction. The two legs are independent, joined together by an adjustable rear handle that hinders rotation between them. Each leg consists of three parts: waist; femoral segment and tibial segment, all adjustable in length. Human-machine interface is obtained with padded orthopaedic splints along each segment, closed by strops.

Actuation is obtained by pneumatic cylinders with cross-connected chambers that operate in agonistic/antagonistic way. In parallel with each actuation group, there is a linear potentiometer that gauges stroke for position feedback, necessary to generate the closed loop control logic commands. The control system is a closed loop position control, activated for each P.I.G.R.O. joint. The digital electrovalves, used to supply cylinders, are controlled by a PWM logic (Pulse Width Modulation).

Fig. 2a. P.I.G.R.O. at work

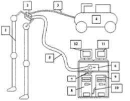

Fig. 2b. P.I.G.R.O. schema

3. SOME EXPERIMENTAL TESTS

P.I.G.R.O. experimental tests have been carried out both without load (person) and with load, using healthy subjects and comparing female and male.

only Bra.Di.P.O., with a MR-compatible construction, can work directly into the scanner. Initially, these long tubes reduce the working frequency from 0.5 to 0.2 Hz. The problem was studied both using a theoretical simulation and then experimentally testing the circuit. A useful solution was finally found putting on Bra.Di.P.O. cylinder two power pneumatic valves, constructed with no magnetic material. In this way, from outside into resonance chamber control pneumatic signals are now only transported, improving dynamic behaviour of the circuit. This allows to obtain working frequency variation from 0 to 0.7 Hz. After the initial testing, P.I.G.R.O. optimisation was also carried out.

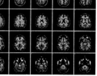

Fig. 5. Some fMRI results from motor learning experiment

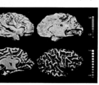

Fig. 6 Other fMRI analysis results on motor cortex

First of all, friction coefficient in the anthropometric slots was improved: this allows to regulate easily distances among joints. Then, some emergency stop bottoms were added in the machine, both for patient and for operator. In this way, when an emergency signal is activated, control software is immediately stopped: a full reset and re-start is required to work again. Finally, an electric motor was put on the back handle to automatically manage the waist corset regulation: in this way operator can easily wear P.I.G.R.O. on patient's legs.

6. CONCLUSIONS

The two prototypes here described have generally a good behaviour both in laboratory and at hospital. In the future, an improvement of the prototypes cons[illegible] the PID control, some tests on disabled people, some electromyography analysis on muscles during treatment would be carried out.

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