THE HYBRID FLUIDIC DRIVEN UPPER LIMB ORTHOSIS - ORTHOJACKET

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SUMMARY

The project ***OrthoJacket*** (OrthoJacket=orthosis jacket) aims at the development of a modular, active orthosis as a portable system for the upper extremity for high tetraplegic spinal cord injured (SCI). The system combines joint stabilisation, external power from flexible fluidic actuators (FFA) with inherent compliance, a grasping function, realised by functional electrical stimulation (FES) and a natural control system that allows the tetraplegic user to regain independence (see Fig. 1). This article introduces the modular hybrid neuroorthosis OrthoJacket.

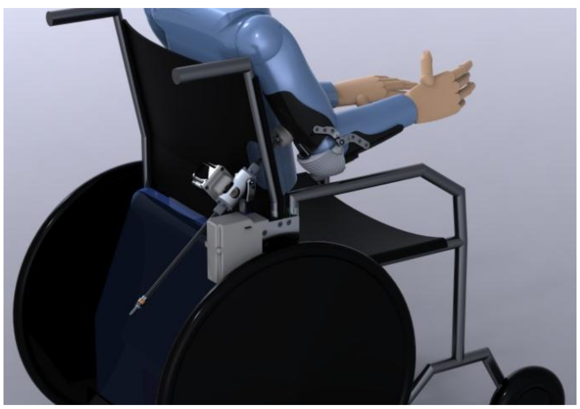

Figure 1: OrthoJacket system, mounted on a wheelchair

INTRODUCTION

Through to the loss of the active movement of the upper extremity, for example a spinal cord injury, patients loose the major part of their autonomy and of their live quality. This leads to a lifelong dependency on caregivers. In the BMBF funded project OrthoJacket a modular, active orthosis for the upper extremity is developed.

The OrthoJacket is primarily intended to be used by high tetraplegic spinal cord injured (SCI) individuals with a cervical lesion (neurological level of lesion C3–C7), which suffer from either complete or incomplete paralysis, eventually with a significant zone of partial preservation or spasticity and spasms. It is aimed as a therapeutic device for enhancement of neuroplasticity in the early rehabilitation phase as well as an assistive device for restoration of persistent functional deficits of the upper extremity. While worn, it will be comfortable and it should be suitable for wearing underneath the clothing.
The primary goal of the wearable orthosis is to improve the paralysed upper extremity function and, thus, to enhance a patient's independence in activities of daily living. The system combines the advantage of orthotics in mechanically stabilising joints together with the possibilities of functional electrical stimulation for activation of paralysed muscles. In patients with limited capacity, for force generation, flexible fluidic actuators are used to support the movement. Thus, the system is not only intended for functional restoration but also for training.

The System consists of an electrically powered shoulder support, a fluid-actuated elbow and a grasping function, realised by functional electrical stimulation (FES). The control of the neuro-orthosis is realised by electromyography (EMG) signals from individually positioned surface electrodes. If there are no measurable EMG-signals, the movement of the orthosis is managed by using a shoulder or neck joystick. OrthoJacket can be used for functional restoration and training at home. By stabilizing the shoulder and the elbow the orthosis relieves the joints, the FES prevents further muscle degeneration and through the active animation joint stiffness is prevented.

GENERAL DESIGN

Depending on the type of the SCI, its location and complexity in the relevant group of patients, the extent of preserved, partially preserved and completely lost functions differs for each patient. Therefore, a modular design is mandatory for the active orthosis to allow for an adaptation and selection of the relevant modules according to the individual status of each user.

For example, a patient with a motor level of C4 needs modules for restoration of the shoulder function, elbow function and grasping function. In contrast to this, a C5 patient typically requires only a module to restore the hand functions, as shoulder and elbow functions are nearly completely preserved.
A major feature of the basic concept of the new orthosis is the individualisation of the actuator components, where several types of actuators are combined for restoration of the relevant motor functions of the upper extremity. To achieve basic grasping patterns and hand functions FES is applied.

In addition, mechanical and fluidic actuators are used together with FES (see Fig. 2), as it has been shown that FES alone is not sufficient to restore elbow and shoulder functions.

COMPONENTS OF ORTHOJACKET

The concept of OrthoJacket based of three modular parts, which can be used individually or together, depends from patient [1].

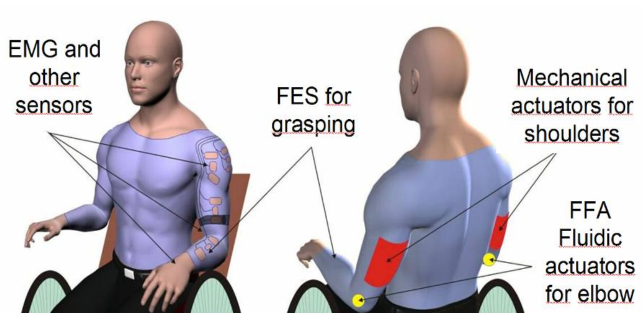

Figure 2: Relevant components of the new orthosis

Hand and wrist module

The movement of the wrist and the grasping function of the hand are achieved by Functional Electrical Stimulation (FES). This type of actuation uses the body muscles to generate the movement. Stimulation is accomplished from outside by special electrodes fixed to the skin above the muscles. Rapid fatigue of the hand is not so critical, because the movements take only very short and no large forces have to be applied [2].

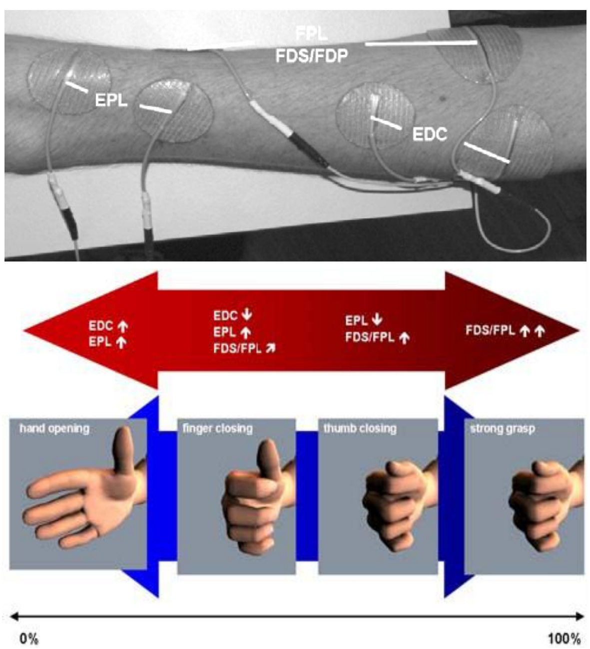

Figure 3: FES electrodes positions and lateral grasp pattern

Grasp function can already be generated by a few surface electrodes, namely three pairs of electrodes for stimulation of the finger extensors (M. ext. digitorum communis EDC), the thumb extensors (M. ext. pollicis longus EPL) and one pair for common stimulation of the finger (M. flex. digitorum superficialis FDS und profundus FDP) and thumb flexors (M. flex. pollicis longus FPL) [3], (see Fig. 3). The muscles controlling the wrist and fingers are located closely to each other in the forearm. Due to the electrode size and inexact positioning of electrodes, not only the relevant muscles, but also adjacent muscles are stimulated. As a result, the wrist direction cannot be adjusted to the desired position. This effect frequently occurs when a simple stimulation system with one electrode pair is applied. The problem is eliminated by the use of several electrode pairs or multi-electrode arrays [4].

Elbow module

At the elbow, the system consists of a lightweight active orthosis that has the potential to be integrated in a jacket. It supports the elbow function up to 100% of the force needed. A series of design studies were needed (see Fig. 4).

Figure 4: Design study of the OrthoJacket powered orthosis with two FFAs on each side of the elbow joint to enable both powered flexion and extension of the elbow (le.) and design with one FFA under use of pressure and vacuum (re.)

For reasons of weight and due to the excellent integrability of FFAs, the orthosis is equipped with these drives that have been developed in the FLUIDHAND project [5][6]. Based on the multibody simulation results, a torque to be applied by the elbow orthosis to move the arm was specified. The actuator meets the required minimum torque amount of 7Nm. The orthosis consists of two composite shells connecting the points of rotation of the actuator with the support area for the upper arm and forearm [7].

Shoulder module

The shoulder function is supported by a linear axle system attached to the wheelchair. The shoulder is actuated by two stepper motors, as the torques to be applied are larger than those at the elbow. The relatively high weight of these drives is compensated by intelligent positioning near the center of rotation of the shoulder system. Shoulder actuation is achieved by a vertical rotation axis for the rotation of the shoulder. Adduction and anteversion are accomplished by an actively driven linear axle fixed to the center of the upper arm to raise the arm (see Fig. 5).

Design of the elbow actuator

As drive a flexible fluid actuator (FFA) is used, because these actuators have a high power density, a small weight, inherent compliance and ensuring safety. Because the actuator is build of several chambers made of film his geometry can be easily adapted to the available space. The new designed fluidic actuator consists of 16 arched and interconnected chambers (see Table 1).

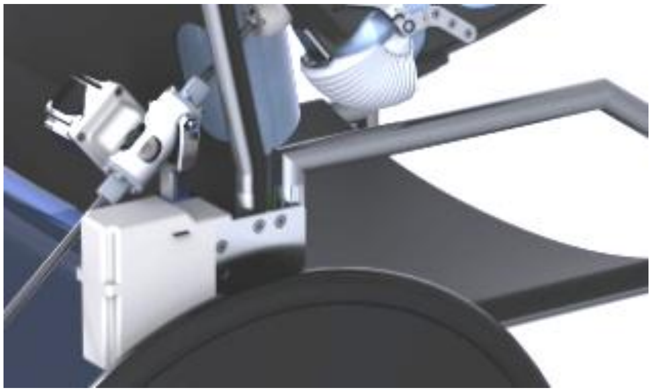

Figure 5: Shoulder module, mounted on a wheelchair

Table 1: datasheet of elbow actuator [7]

Weight	33.2	g
Air volume	16x126 =	mm^3
Air volume	0.020576	l
Thickness at 0 kPa	17	mm
Thickenss at 100 kPa	180 (mechanical stops)	mm
Angle	130 (mechanical stops)	^{0}
Operating pressure	200-300	kPa
Maximum pressure	400	kPa
Burst pressure	960	kPa
Assembly	16 Chambers	
Area per chamber	1737	mm^2

That assumes the shape of a hemisphere under pressure. At each end of a chamber a strap is attached, which serves for the mechanical guide of the actuator. The straps are connected together and rotary associated with the joint axis. Hence, it can be integrated easily in a piece of clothing and hardly interferes with the natural aspect.

For flexion, the actuator is pressurized with an overpressure of up to 400kPa. Extension requires a smaller torque, because it is not necessary to defy gravity. Consequently, 90kPa partial vacuum is sufficient to move the forearm back to the 0_ position. Exact pressure adjustment between -90 and 400kPa is accomplished by a proportional valve. It is located together with the pump and the storage tank for compressed air in a sound-proof container below the seat of the wheelchair [7].

For the measurement of the elbow joint angle a digital angle sensor, based on the Hall Effect, is used. It determines the current angle with a resolution of 12bit.

CONTROL OF THE ORTHOSIS

As the OrthoJacket represents a system with up to 6 degrees of freedom, control is rather complicated for paraplegic patients who have a limited number of usable random signals only. Two different types of random signal sensors are used. If possible, OrthoJacket is controlled by electromyography signals (EMG signals) measured at the skin surface of the patient. There are two approaches to control the orthosis via EMG-signals. If the patient has some remaining voluntary movement in his muscles, for example in the musculus biceps brachii, then the EMG-signal is measured at the muscle the patient wants to move. This kind of control is very intuitive but not always possible, because not every patient hast remaining voluntary movement in the arm or shoulder muscles. For these patients it is still possible to control OrthoJacket via EMG-signals. Here the signals will be taken from muscles with remaining voluntary movement, like the musculus frontalis at the forehead. With a headband with textile EMG-electrodes a frown can be detected and can be translated in a movement of the Orthosis [8].

A second possibility of signal acquisition is to use a joystick fixed on the shoulder or neck. This joystick can detect even smallest movements. As it is impossible to extract a target value for the desired end position from these signals, a speed-proportional control is implemented. When the random signal exceeds a certain patient-specific limit value, the corresponding actuator is activated. The more the current value of the signal exceeds the limit value, the more quickly the orthosis will move. This process is illustrated by an EMG signal in figure 6 below. More details and different modes for the joystick control are described in [9].

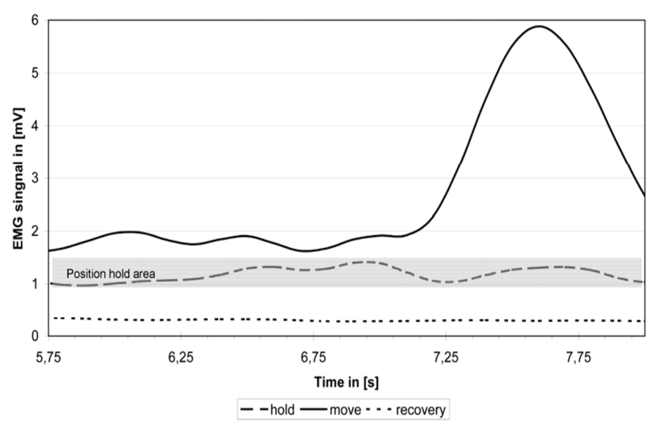

Figure 6: EMG signal at the biceps [9]

EVALUATION

First tests of the system were made with healthy subjects, (Fig. 7). In these tests, it was determined how large the movement space of persons of variable size is and system operation with limbs of variable weight was evaluated. Three persons with complete movability were chosen to represent a very large group of persons. Their weights ranged from 63 to 95kg, their size varied between 1.84 and 1.92m. The results obtained were very good, as you can see on table 2. In case of adduction, the wheelchair to which the system was fixed prevented further rotation to the outside.

Table 2: Results of the evaluation [9]

Patient	Results of the test			
	Weight in [Kg]	*Size in [m]*	*Ante version in [°]*	*Adduction in [°]*
1	63	1.84	0 to 76	-20 to 29
2	84	1.88	0 to 71	-18 to 30
3	95	1.92	0 to 51	-12 to 29

Tests on patients focused on the elbow orthosis. The patient has a lesion below C4 and voluntary movement of the biceps was very difficult. Voluntary activation of the triceps was impossible. With the orthosis flexion and extension of the elbow was between 0° to 90°. The elbow orthosis was controlled by a shoulder joystick. In the patient test, it was checked how intuitive the control of the orthosis is and how reliably it can be moved. When the joystick signal exceeded a certain threshold value, the pressure in the actuator was increased slowly. When the signal dropped below the value, the movement stopped. The results were satisfactory, but also showed that the patient first requires a training phase to learn to control OrthoJacket.

Figure 7: Test of the shoulder- and elbow modules

CONCLUSION

First experiments showed that the elbow orthosis is considered helpful and useful by the patients. Now, the complete OrthoJacket system with the shoulder actuators remains to be evaluated on healthy subjects and on tetraplegic patients. For this purpose, a test scenario was designed with activities frequently occurring in everyday life. The test person is sitting in his wheelchair in front of a table and wishes to grasp a drinking vessel and move it to his mouth. This movement that is important in everyday life is repeated several times using the different operation modes of the OrthoJacket. With this, it will be tested whether the system will also work reliably in the human environment to get a feedback how the patients has experienced the system.
The design of the OrthoJacket will focus on both functionality and aesthetics. The aesthetics play a major role in the development process, because they affect the patients' acceptance of the new device. Therefore, a distinct focus of the OrthoJacket lies on miniaturisation of the designed components and their integration in textiles.

ACKNOWLEGMENT

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