

A SIMPLE ONE DEGREE-OF-FREEDOM FUNCTIONAL ROBOTIC HAND ORTHOSIS

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Abstract

Individuals who have suffered cervical spinal cord injury (SCI) usually lose the ability to manipulate objects in a reasonably efficient way. In order to be able to perform simple tasks, they must resort to specially designed passive devices. This paper describes the design and implementation of a one degree-of-freedom functional hand orthosis. The main objective was to develop a simple, inexpensive, adaptable device that would help in restoring the precision grip capability of individuals with SCI. Several experiments of the grasp-and-release type were conducted with different objects, and preliminary results that show and quantify the improvement in an individual's gripping abilities are presented.

Introduction

The human hand is an impressive device that is essential to the interaction with the physical world. Its importance is evident in communication [1] and cognitive processes. The ability to manipulate small objects is very important in general, but is fundamental to the activities of daily life (ADL). In the

school environment, for instance, the hand can be seen in action in the manipulation of objects such as pens, erasers and books. In order to manipulate small objects, the hand executes a movement that is known as *precision grip* [1]. This type of grip has an important role in the execution of several ADL. One such a precision grip called the bidigital grip is very important and is present in about 20% of the ADL [3]. Among the bidigital grips, the pinch grip, which is performed with the index and thumb fingers, is the most frequently used.

Individuals with C5-C6, C6 and C6-C7 SCI are usually able to move and position their hands in free space and in most cases, are also capable to control wrist movements such as extension and flexion. Unfortunately, such individuals lack the ability to efficiently and adequately grasp and release common objects. Often this inability is one of the main reasons which hinders such individuals from undertaking professional, social and personal activities.

This work presents the design and implementation of a simple and inexpen-

sive device that significantly improves the ability of an individual to perform bidigital grips between thumb and index fingers (pulp-to-pulp pinch). A simple orthosis prototype was built in order to assess potential functional gain. Preliminary results compare favorably to *tenodesis* (a type of synergy where the wrist extension causes a flexion of the fingers (to grasp) and the wrist flexion causes and extension of the fingers (to release) [4]) alone, in object manipulation tasks.

Background

SCI individuals usually grasp and release objects using tenodesis. However, tenodesis alone is limited since both the aperture and grasping of fingers are passive and depend, among other factors, on the tension applied to the tendons and ligaments of the fingers [5]. Hand orthosis [6] and neuroprosthesis [4, 7] are alternatives commonly used to (partially) restore the functionality of the hand.

Several promising alternatives of devices that were designed to assist in the recovery of functionality of SCI individuals have been reported in the rehabilitation robotics literature [2, 8, 9, 10]. Nevertheless, considering the large number of devices that have been proposed, it is very disappointing to verify that only a few were effectively useful. According to Kumar *et al.* [2], this situation can be explained by the high costs involved in building sophisticated robotic contraptions, by awk-

ward interfaces with the user and by the social stigma of robots. A low-cost, functional and user-friendly orthosis, which can be aesthetically improved in order to be less apparent was designed.

Methodology

The prototype of the orthosis is depicted in Figure 1. The structure was built from low-temperature thermoplastic [6], which has as main advantages the low-cost, light-weight and shape adaptability. The structure is composed of three parts (links) connected by one actuated joint and one passive, instrumented joint. The last link keeps the thumb in a fixed position, that allows the closing of the grip only with the movement of the index finger. Actuation of the joint corresponding to the metacarpophalangeal joint (MCP) of the index finger and its consequent movement, is provided by a directly coupled DC servomotor. A potentiometer, approximately located on the flexion-extension axis of the wrist, informs the angular position to a microcontroller, which is actually the set point of the control system.

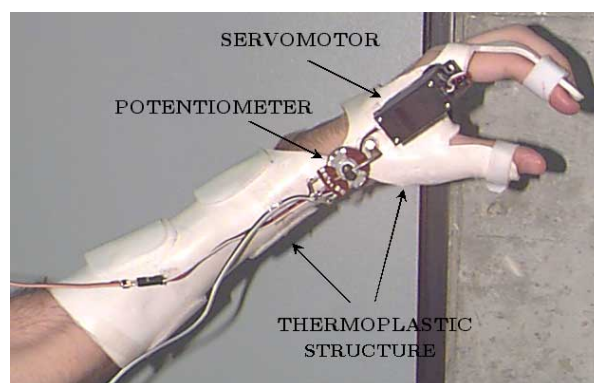


Figure 1: The prototype and some of its components.

The device has only one artificially actuated degree of freedom at the MCP joint and two passive ones at the wrist joint. The last two allow for a free movement of the wrist during the flex-extension, while permitting for limited freedom of movement of radio-ulnar joint (arrow in Figure 2). Removing the constraints provides a more comfortable use of the orthosis.

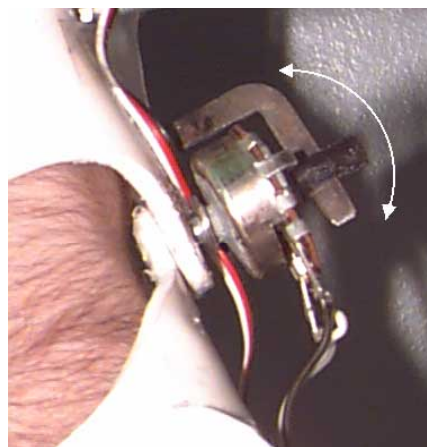


Figure 2: Potentiometer assembly. Arrow indicates radio/ulnar typical trajectory.

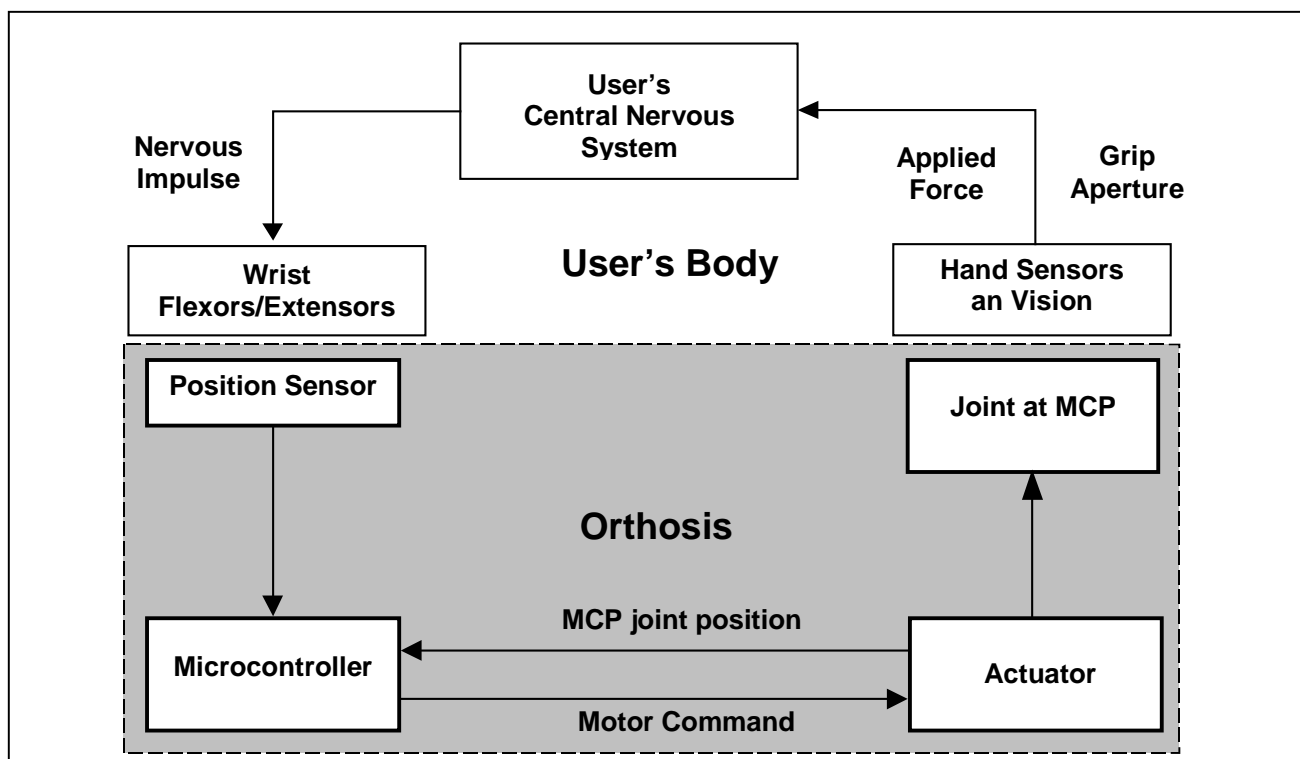


Figure 3: Orthosis block diagram.

User control of the orthosis

Orthosis control by the user is very simple and natural. Simplicity results from the fact that there is only one degree of freedom to control. One of the important features is that control is

very natural to the user since standard tenodesis movements can be used. This also greatly improves learning time to control the device. A block diagram of the system and its interaction with the user is shown in Figure 3.

Gripping is executed by extension movements of the wrist. The central nervous system of the user sends impulses commanding the wrist to be extended and also the fingers to flexed. Wrist rotation is measured by the position sensor (potentiometer) which is converted to angular displacement (*set point*) by the control unit. A simple *PD* control algorithm receives as input the wrist position and sends control signals to the servo. The servo applies torque to the joint corresponding to MCP joint of the index finger, which causes grip closure around the object. Prior to finger-object contact, proprioceptors of the individual's hand and vision are the main sensors used to control the grip aperture. In the mean time, the position sensor sends off to the automatic control system the angular position of the wrist joint. After contact is made between the object and the hand, higher prehension forces can be achieved by moving the wrist sensor further in the same direction. From that point on, force sensing is provided by the individual's hand tactile and force sensors. Hence, the *cutaneous - proprioceptive - visual - robotics* loop is able to provide full control of the orthosis. This loop is extremely important to the acceptance of the orthosis by the user as well as to minimize learning time to control the device. One of the reasons for is the inclusion in the loop of the cutaneous and proprioceptive sensors of the user. That happens because the feedback is done by organs of the very body of the user, who can sense the

object manipulation. The counter-opposition (to open the fingers) is executed in a similar way, but it uses the wrist flexion movement.

Results

Initial observations of the benefits of the orthosis suggest that it provides a good gain in functionality, allowing the user to execute important tasks such as feeding and writing.

In order to quantify the functional gain, a test of grasp-and-release was conducted. The test is described as follows and further details can be found in [5, 11].

Grasp-and-release Test

This test is performed in sessions. Each session consists of testing each object 5 times with and without the orthosis. Subjects are requested to complete a maximum number of tasks within 30 seconds trials. The number of successful completions and failures are recorded for each trial. Objects are tested in random order to minimize systematic errors or successes due to fatigue or learning by the subject. A gap of 30 seconds was kept between trials.

Object	Weight (N)	Size (cm)	Material
Peg	0.0196	0.71 (dia.) × 7.6	Wood
Block	0.0981	2.5 × 2.5 × 2.5	Wood
Can	2.207	6.5 (dia.) × 12.2	Aluminum
Video tape	3.286	3.0 × 12.3 × 22.5	Plastic

Table 1: Test objects.

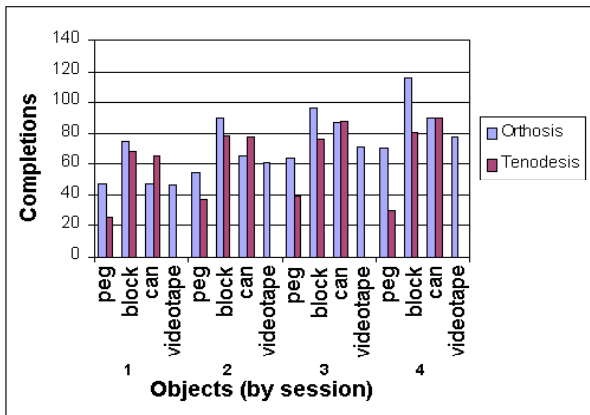


Figure 4: Grasp-and-release tests. Successful completions. Columns show scores for 5 tests in 4 sessions.

One subject, with C6-C7 level injury, participated of the tests. The subject has a good control of the upper limbs. The orthosis was worn on his left hand (non-dominant), while the right hand (dominant) was used to perform the tests without the orthosis. That is justified by the fact that we are comparing the functional capability of a hand supposedly less dexterous but worn with the orthosis (left), with the other hand supposedly more dexterous, since it is the dominant one, but without the orthosis (right).

Grasp-and-release Test Results

Figure 4 presents some results for the four sessions of tests conducted during four consecutive days. It can be noticed that the performance with the orthosis was consistent and superior to that of with tenodesis alone. The subject's learning curve can be observed in the grasping of a can, where the performance using the device gradually

became similar to tenodesis. The most remarkable differences are seen for the both the peg and videotape. The later could not be manipulated in no one of the sessions, without the orthosis.

The number of failures with the orthosis were quite small, as seen in Figure 5. This is mainly due to the learning process the subject went through as he tried to execute the maximum number of tasks within the allotted time for each trial. Indeed, in the first session no failures were observed with the orthosis. The difference is substantial both for the peg and the videotape. Furthermore, for the later not even a single failure was registered.

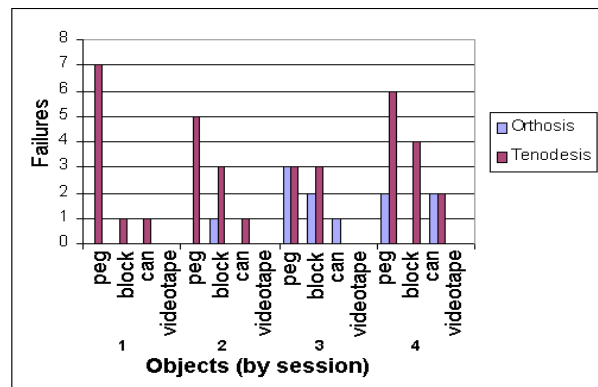


Figure 5: Grasp-and-release tests. Failures are shown by session. Columns show the scores for the 5 tests in 4 sessions.

Conclusion

The design and implementation of prototype of an orthosis was presented here. The main features of the device are its performance, low cost, easiness of use and adaptation to other individuals. Preliminary results of the grasp-and-release test suggests that the orthosis provides real functional gain

for its user. Evidently, more tests are necessary with a reasonable sized population of subjects. However, in despite of that, the subject that underwent the experiments was very satisfied with the performance and easiness to use presented by the device, to the point that he had motivation to use it in his daily life. Mainly, this is due to the fact that the device feels comfortable, it is easy to control, it is easy to wear, it also provides firmness during manipulation and, most importantly, enables the execution of tasks that otherwise could not be performed (like the videotape manipulation during the tests). Some problems need to be addressed in order to make the orthosis more acceptable to the user, and the main one is to move the servomotor from the hand to a more proximal position in the forearm. This can be accomplished by simple modifications to the current design.

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