ANALYSIS AND DESIGN OF AN ARM ORTHOSIS FOR INDIVIDUALS WITH MUSCULAR DYSTROPHY

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Abstract

For people with muscular dystrophy and spinal muscular atrophy there is a need for a mechanism to support the weight of the persons arm against gravity and allow either residual muscle force or external power to position the arm in space. The current generation of clinical devices, such as the balanced forearm orthosis (BFO), allows this movement primarily in a horizontal plane. This paper presents one method that allows a person to balance the weight of his or her arm against gravity and thus allows for a wide range of vertical movements.

Careful design of an orthosis based on the mechanism discussed allows the orthosis to be externally powered should residual muscle forces be insufficient to perform the tasks required by the user. A powered orthosis test-bed is described in this paper that allows a variety of power assist ideas to be evaluated. This upper arm orthosis test-bed is based on an RT200 robot.

Introduction

Disabilities such as muscular dystrophy affect the strength of a person's muscle, yet leaves sensation and residual muscular control intact. It is hypothesized that augmenting residual arm function rather than replace it with a robot is a more effective solution for an assistive technology. An ongoing project within the robotics laboratory of the Applied Science and Engineering Laboratories (ASEL) explores methods of augmenting function via a powered orthosis that can support a person's arms against gravity and provide a full range of arm movement. Control of such an orthosis is achieved either by amplifying the person's residual strength or by using signals obtained from other body sites. Residual hand function is important and, although under study within this effort, is not covered in this paper.

Individuals with either total paralysis or absence of sufficient muscle tone for performance of desired arm function are the focus of this study. The aim for the final system is to mount the orthosis on a wheelchair. This decision both suits the needs of the target population and makes the engineering a more tractable proposition.

Background

The terms powered orthosis, extender or orthotic telemanipulator refer to a class of assistive robots that support and move the arm of a person in order to augment function.

The first research on rehabilitation applications of such devices was done at the Case Institute of Technology in the early 1960s [1,2]. A powered exoskeleton was fixed to the floor and controlled via a head mounted light source that triggered light sensors in the environment. This device could do preprogrammed tasks or be moved directly by the individual.[1] This work led to the Rancho 'Golden' arm, developed at Rancho Los Amigos Hospital, in 1969[3]. This was a six degree-of-freedom powered orthosis that used seven tongue switches in a sequential mode to successfully maneuver the arm in space.

The concept of the wheelchair mounted powered orthosis resurfaced in the U.K. in 1987 when Hennequin presented a prototype powered arm support that used a novel pneumatic actuator to assist movements of the person's right arm [4]. The device was controlled by direct control of the actuator joints via a switch pad operated by the person's left hand. This project was transferred to the design center of the Engineering Department at Cambridge University U.K. where it became a design project intended to evaluate new design methods. This orthosis moves the persons arm against gravity while allowing unconstrained arm movements in the horizontal plane [5].

The Balanced Forearm Orthosis (BFO) developed in the fifties is currently the most popular body powered orthosis in clinical use. The basic design limits the person to working in a horizontal plane, although the balance point does allow a skillful person to reach his or her mouth to assist with eating.

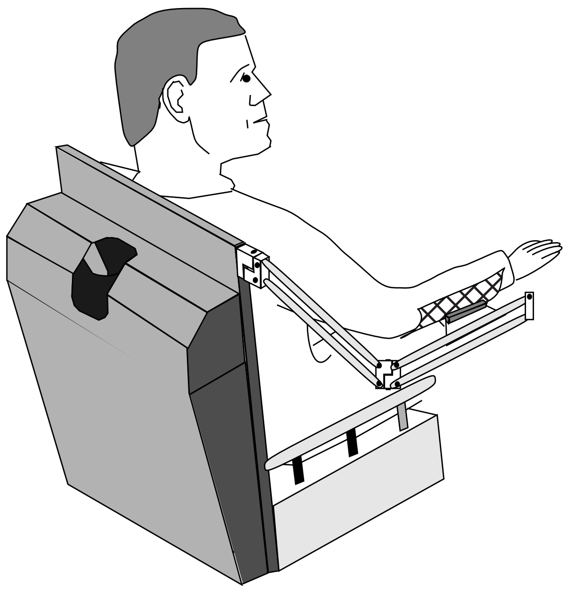
Objective

This project intends to create the engineering knowledge for a range of body and externally powered orthosis designs that are modular and mount on the person's wheelchair.

This engineering knowledge must relate the device to the way it is used. Further, the success of such a device depends on the interface between the person and the machine and it is vital that the person is able to predict the behavior of the device during operation. Understanding of this interface is a further goal of this research and a test-bed is used to prototype and evaluate interface strategies.

Evaluation of the kinematic and aesthetic concept done via a series of virtual and physical prototypes that allow directed and appropriate feedback from consumers (users, families, care-givers and clinician). Methods must be developed to ensure this is done in a cost effective manner. An initial concept drawing of what the eventual device might look like is given in Figure 1.

Figure 1: Concept drawing of arm orthosis



Approach

A key element of this project is the timely and appropriate input in the design process of the end users of the target product along with the family, care-givers and rehabilitation professionals.

In April and July of 1994 a forum for ideas was initiated where children with spinal muscular atrophy and muscular dystrophy and their families and care-givers were invited to participate in a series of brainstorming sessions to identify areas of need and the potential of an upper arm orthosis to meet these needs. The results of this focus group are documented in a Technical report [6].

Among the concerns expressed by consumers was simplicity and portability of any robotic device. There are also clear advantages to augmenting existing functions rather than attempting to replace function with a robot when a person retains some residual motor and sensory function. Moreover, even when such sensory function is absent, the psychological merit of the use of an orthosis versus a purely robotic system is important.

Results

Body Powered Orthosis Design

The underlying mechanism proposed for the design of a practical upper arm orthosis is shown in Figure 2. Either a static analysis or energy methods can be used to show that given a linear spring

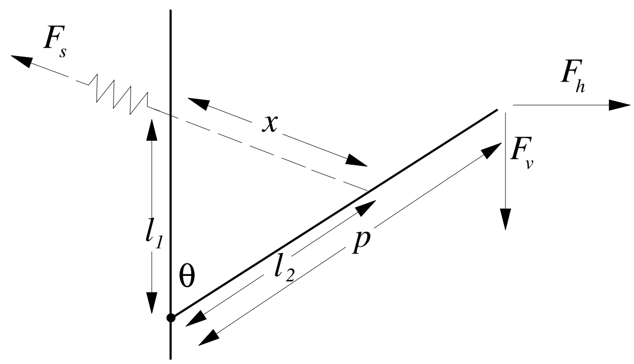
$$F_s = K_0\,(x - x_0)$$

where F_s is the spring force, x_0 is the rest length of the spring, and K_0 is the spring constant, the system is in equilibrium when

$$\frac{K_0 l_1 l_2}{p}\left(1 - \frac{x_0}{x}\right) = \left(F_v + F_h \cot\theta\right)$$

Two terms in this equation depend on θ, $F_h\cot(\theta)$ and x_0/x. Both these terms can be designed out of the mechanism, by minimizing horizontal forces, and by arranging for $x_0=0$. The remaining force, F_v, consists primarily of the weight of the person's arm along with any residual forces that are used to move the mechanism up and down, i.e. $F_v=Mg+F_r$.

Figure 2: Static analysis of mechanism



This results in the weight of the person's arm being supported by the mechanism independently of the position of the arm. Additional properties can be intentionally added to the mechanism. For example an additional load can be accommodated by adjusting l_1 or l_2, likewise a controlled stiffness can be induced by having a non zero value for x_0.

Practical considerations however dictate some compromises. For example, the spring may have non-linear characteristics and the mechanism's kinematics must be aligned with the kinematics of the person's arm.

Three physical prototypes have been developed, similar in shape to the concept drawing shown in Figure 1. These prototypes have demonstrated the feasibility of this approach and have received limited informal evaluation. Work is now progressing towards a prototype mechanism that can be taken through a more formal short term clinical evaluation.

Externally Powered Orthosis Test-bed

A body powered orthosis is likely to be effective for people with certain classes of disabilities but does not fulfill all the requirements of a device intended to assist people with degenerative muscular conditions such as muscular dystrophy. The design of the body powered arm orthosis should have the necessary modularity so that actuators can be added to accommodate for progressive loss in function. To meet this design goal, and establish human machine interface criteria for an external power assisted orthosis, a test-bed has been established based on a modified SCARA robot arm. This test-bed, built on an RT200 (Oxford Intelligent Machines Ltd. UK) can simulate a wide range of possible powered orthosis configurations. The gripper of the robot has been replaced with a force sensor and an arm support. Software was written that measures residual forces generated by the person on the orthosis and uses these forces in the control structure.

A variety of relationships between the exerted force and the movement of the orthosis have been evaluated such as relating force to position, force to velocity and force to acceleration. More complex relationships have also been developed such as relating impulse to velocity via a pseudo mass.

This test-bed was demonstrated at the 1994 focus group meetings. Children with spinal muscular atrophy and muscular dystrophy were invited to use this test-bed in a number of ways. They were all impressed that they could move a large and powerful machine with a minimal force.

The flexibility this test-bed allows in prototyping the human machine interface has been valuable in assessing the design of both the body and the external powered orthosis. It has highlighted the need to understand the conditions for stability for an orthosis, and has shown how an intuitive interface can be established. Further areas of exploration with this test-bed include prototyping and assessing different interfaces strategies.

Discussion

The use of a test-bed has proved a valuable method to assist with the design of a powered upper arm orthosis. Although certain aspects of the body powered mechanism are difficult to prototype, such as dynamic behavior, the test-bed does allow us to assess possible ranges of motion and the need for gravity compensation. It also allows evaluation of interface strategies for an external powered orthosis. These ideas can then be incorporated in the designs of the body powered orthosis. A practical clinical upper arm orthosis design is ongoing at the ASEL based on the sine mechanism. The design is intended to be modular so that external actuators can be added if needed to account for the progressive loss of strength because of a disease such as muscular dystrophy.

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