# Consumer Criteria for an Arm Orthosis

Tariq Rahman, Sean Stroud, Rungun Ramanathan, Michael Alexander, Rami Seliktar and William Harwin,
Applied Science and Engineering Laboratories, University of Delaware /Alfred I duPont Institute, Wilmington, DE 19899, USA.

**Abstract**

For people with muscular dystrophy and spinal muscular atrophy - conditions characterized by degenerating muscle strength - there is a need for an exoskeletal mechanism that allows the person to move their arms about freely. This paper presents a consumer-based design approach in order to construct such an assistive manipulation device and details the initial stages that have been addressed in an orthosis design project within the Applied Science and Engineering Laboratories. Two consumer meetings were held during the initial stages of the design. The results from these meetings are presented. A design principle has been established and an initial set of prototypes evaluated. These will be used to modify subsequent design iterations.

**Introduction**

Disabilities such as muscular dystrophy affect the strength of a person's muscles, yet leave sensation and residual muscular control intact. It is hypothesized that augmenting residual arm function, rather than replacing it with a remotely controlled device such as a robot, is a more effective solution. 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 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.

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 have an orthosis that can be mounted to 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’ are all given to a class of assistive robots that supports and moves the arm of a person with upper extremity paralysis in order to augment all residual 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 four degree of freedom powered exoskeleton was fixed to the floor and controlled via a head mounted light source that triggered light sensors in the environment. A series of preprogrammed movements were stored on a magnetic tape and were used to move the arm in response to the light sensors. A second version added Cartesian movements and included light sensors on the arm to allow direct movement of the joints. This version used myoelectric signals to control the velocity of arm movements.

A $CO_2$ powered arm developed at Rancho Los Amigos hospital led to the six degree of freedom electrically driven Golden Arm [3]. The Rancho Golden Arm had a similar configuration to the Case Arm but lacked the computer control, relying on joint level control of the arm. It was significant, however, in that it was mounted on a wheelchair and was found to be useful by the people who had disabilities resulting from polio or multiple sclerosis and still had intact sensations. The Rancho Golden Arm was controlled at joint level by seven tongue operated switches, the seventh of which controlled an additional gripper. Leifer [4] noted that the Golden Arm was difficult to control and unreliable. Reswick, however, remarked on the profound success of the underlying thesis. The success of the Case Arm and the Golden Arm, in contrast to the subsequent robotics work, was due to the vital role that proprioceptive feedback plays in the control of a human extremity.

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 [5]. 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 one of the flagship design projects to test new design methods [6].

Work at the University of British Columbia is ongoing on a body worn powered orthosis for people with flaccid arms. Initial work has identified the kinematic characteristics of the orthosis based on a set of daily living tasks and a protoype is in development [7]. This work is based on an orthosis designed at the Hugh McMillan Medical Centre in Toronto.

Homma and Arai have studied a parallel mechanism for an upper limb orthosis based on suspending the persons arms by six independently actuated cables from an overhead support. Their target population are elderly disabled people and initial work has studied the workspace available for this class of mechanism [8].

In clinical practice 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 be able to predict the behavior of the device during operation.

Evaluation of the kinematic and aesthetic concept is done via a series of virtual and physical prototypes that allow directed and appropriate feedback from consumers (users, families, caregivers and clinicians). Methods must be developed to ensure that this is done in a cost effective manner.

**Consumer Meetings**

Two meetings were organized in the Summer of 1994 where people with Spinal Muscular Atrophy

(SMA) or Duchenne's Muscular Dystrophy (DMD) were brought together along with their families or caregivers. The objective of the meetings was to explore the preferences of people with muscular dystrophy and their families with regard to the kind of assistance which the orthosis should provide. Four families attended the first meeting and five families attended the second meeting. Table I presents some data about the participating subjects. Ages ranged from 5 to 23 years with a median age of 13.5 years. All but one subject were male.

The meeting was started with the question "What activities would you like an orthosis, brace or machine to help you do, that you cannot do for yourself now?". The question was phrased so as to avoid bias towards a particular type of device, problem or solution. First the participants were solicited for ideas, followed by the caregivers and parents. This sequence continued until all ideas were exhausted. All responses were recorded on flip-charts.

Once a first round of ideas had been completed the meeting adjourned for a tour of the rehabilitation robotics laboratory at the Applied Science and Engineering Laboratories. This tour demonstrated a wide range of solutions to the problems encountered in manipulation. For the purpose of the laboratory tour and presentation of the hardware, five workstations were organized as follows;

Station 1: Balanced Forearm Orthosis (BFO) and overhead slings

Station 2: RTX robot test bed, for a powered orthosis with one joint activated

Station 3: A prototype of our exoskeletal orthotic system equipped with an anti-gravity mechanism

Station 4: A painting robot

Station 5: MANUS robot (only in second meeting)

A lunch followed the tour during which time the team had an opportunity to observe the strategies used by the participants to eat. Six of the ten participants could eat on their own. One of the six participants could eat by himself, if his food was cut into pieces. One participant used a BFO to feed himself. Four of the participants used the edge of a table as a support to feed themselves. Three participants were fed by one of their parents, while one of them did not eat.

Following the laboratory tour and lunch, the meeting reconvened and participants were encouraged to re-evaluate ideas from the earlier brain storming session and generate new ideas with a greater technological focus.

The list of ideas was then expanded using data from surveys done by Stanger [9] and Prior [10] and an aggregate list of suggestions presented to the group. The final stage was to ask the participants to rank their own top five choices from this aggregate list of tasks.

**Findings and Recommendations**

Table 2 gives the tasks from both meetings, ranked by priority. Tasks were often either identically defined in both meetings, such as “talking on the phone”, or were very similar, such as “Reaching and picking things from a shelf” and “Reaching beyond a close range”.

Most of the tasks suggested by both participants and parents were practical, realistic and recognized the limitations of assistive technology. Some ideas however, were ambitious and impractical. These were primarily put forth by some of the younger participants. In general, however, the participants were much more reserved than the parents, the latter offering the most input. The wishes could be divided into several categories: (1) assistance with immediate needs, which was a concern voiced by both participants and parents; (2) preparation for future loss of function or problems which could arise from growth, which were primarily the concern of the parents; (3) Transfer into and out of the wheelchair, which is a common concern of individuals who use mobility aids; and (4) safety issues.

The participants and parents were generally receptive to the idea of using an “extra arm” for their daily management, however the general preference was an exoskeletal orthotic system, rather than an autonomous assistive robot. A device that could “...exploit the muscle forces of the user to the maximum extent." On the other hand, when it came to functionality considerations, there was no insistence on the part of either participant or parents that the arm function would be confined to conventional arm performance, one of the most common problems was identified to be the retrieval of objects from the ground. There was no objection to the use of an arm which will extend beyond the range of the normal arm and will reach the ground without the need for the torso to bend forward.

Leaning forward was identified as a general concern, particularly of individuals who already had considerable trunk muscle weakness. A few of the subjects were totally unable to recover from such leaning without assistance. At least in one case, an individual's caretaker/mother, expressed concern that while she was at work, and her son was unattended, he might remain for hours in a slumped-forward posture. She expressed a desire that the orthosis should enable her son to correct his sitting posture. This was one of the issues which had not been considered by the team. Parents/caretakers of the heavier participants were particularly concerned about the transfer issue. Some of the parents also suggested that the project staff spend at least one day with the families in their own environment.

**Prototype Designs**

The objective is to develop an upper arm orthosis that can be either body powered or use an external power source to assist with arm movements. At stage (1), the consumer meetings helped develop preliminary specifications; at stage (2), prototypes of an un-assisted, exoskeletal, gravity compensated system was developed and is still in progress; at stage (3) subject testing with the exoskeletal system will be performed, to determine kinematic arm/orthosis compliance and further needs for power assistance; at stage (4) an external power control scheme will be developed, considering the command signal interface and the driving (power assist) technology; and at stage (5) a prototype powered arm will be constructed and evaluated with the corresponding consumer population. Safety of operation will be constantly tested and re-evaluated prior to any subject testing.

The following describes the prototypes that resulted from the knowledge accumulated during this initial period and from the interaction with the consumer groups. The consumer meetings confirmed the need for a device that supports the weight of the person's arm. The existing BFO accomplishes this only in the horizontal plane. The design team had constructed a gravity-balanced prototype that allowed for movement to all points in the arm's workspace.

The purpose of an anti-gravity mechanism is to allow an object, such as a lamp or a person's arm, to be positioned in space with *minimal* effort, and to maintain that position with no external forces.The first two body powered arm orthosis prototypes are based on the principle of an anti-gravity mechanism [11,12]. The mechanism uses linear springs to compensate for the weight of the arm, as shown in Figure 1. One advantage of this design over previous ones is that gravity compensation is provided perfectly, for the complete range of joint rotation (θ).

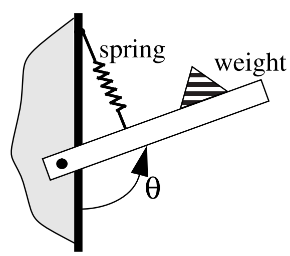


Figure 1 - Principle of anti-gravity mechanism

This anti-gravity principle was extended to two parallel bar mechanisms (one for the upper-arm, the other for the forearm) as shown in Figure 2, where one spring balances each parallel bar. The first prototype was built [13] which successfully demonstrated the anti-gravity concept by balancing simulated arm weights. Bungees (rubber) cords were used instead of linear extension springs. For compactness, the bungee cords were mounted at the back of the wheelchair and connected by cables to the orthosis. Although this mechanism successfully proved the anti-gravity concept, it was not geometrically or structurally sound and could not be evaluated by potential users.

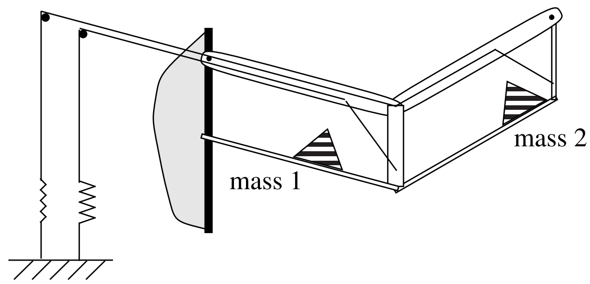


Figure 2 - First prototype, anti-gravity mechanism using parallel bar linkages

A second body powered orthosis prototype was designed and constructed with the intent that it be user tested. As illustrated in Figure 3, two parallel bar mechanisms arranged serially were also chosen for this design. In this design springs were located inside the mechanism to minimize cable friction and improve cosmesis.

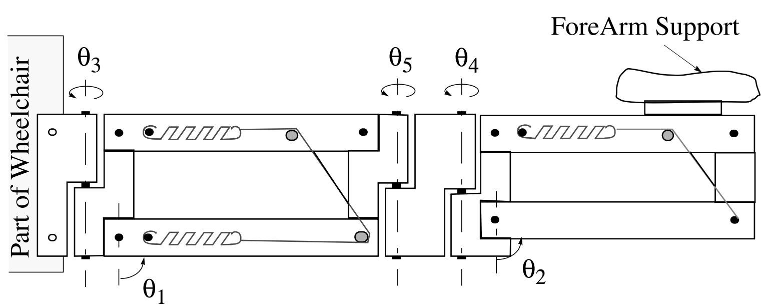


Figure 3 - Second prototype - body powered orthosis design

As shown in Figure 3, the orthosis has five basic motions. Each parallel bar linkage can rotate about $\theta_1$ and $\theta_2$, respectively. Additionally, pin joints provide each parallel bar linkage with a rotation about a vertical axis ($\theta_3$ and $\theta_4$). Lastly, a hinge component is provided between the two parallel bar mechanisms giving an additional rotation about a vertical axis ($\theta_5$). The joint, $\theta_5$, is provided to allow the joints of the mechanism to closely align with the user's elbow joint and hence, reduces relative motion required between the user's arm and orthosis. A support is present at the mechanism's end for attaching the orthosis to the user's forearm.

### Discussion and Future Work

The use of other spring configurations and other types of springs such as, torsion, constant force, gas, compression springs, and bungee cords are being explored so that the orthosis can be made smaller. Analysis is being conducted to decide the number, location, and type of orthosis/human attachments and to determine the orthosis configuration for it to comfortably conform with the user's arm. Two obvious safety concerns to be addressed with the current design include pinch points within the parallel bar mechanism and a safety constraint in case a cable or spring breaks. Variation in the kinematic design is also ongoing and additionally, a means of powering the mechanism through electric motors and springs, is being investigated.

Most tasks do not require the orthosis to support large loads with respect to the persons arm and should lead to a simpler design. Similarly most tasks identified in the survey require some grasping ability and this must still be addressed in our work. A suitable orthosis will have utility in many areas including recreation, light weight tasks in personal hygiene and general reaching. Other mechanisms or ongoing reliance on attendant care will be required for tasks such as independence transfer.

### References


[1] Maurice LeBlanc and Larry Leifer. Environmental control and robotic manipulation aids. Engineering in Medicine and Biology Magazine, pages 16–22, December 1982.

[2] James B. Reswick. The moon over Dubrovnik - a tale of worldwide impact on persons with disabilities. In Advances in External Control of Human Extremities, Dubrovnik, 1990.

[3] James R. Allen, Andrew Karchak, Jr., and Ernest L. Bontrager. Design and fabrication of a pair of Rancho anthropomorphic arms.Technical report, The Attending Staff Association of the Rancho Los Amigos Hospital, Inc, 1972.

[4] Leifer, L. Rehabilitative robots. *Robotics Age*, May/June 1981 pp. 4–15

[5] Jim Hennequin, Robin Platts, and Yvonne Hennequin. Putting technology to work for the disadvantaged. In Rehabilitation Robotics Newsletter. The Rehabilitation Robotics Research Program, Applied Science and Engineering Laboratories, Alfred I. duPont Institute and the University of Delaware, 1992. Vol 4(2).

[6] Bauert, F. The Mobile Arm Support Phase I: Design, Manufacture, Testing. Technical Report CUED/C-EDC/TR 13, Cambridge University Engineering Department. 1993

[7] Romilly-Douglas-P. Anglin-Carolyn. Gosine-Raymond-G. "Functional task analysis and motion simulation for the development of a powered upper-limb orthosis", IEEE Transac-

tions on Rehabilitation Engineering Vol 2(3), Sep 1994. p 119-129

[8] Keiko Homma and Tatsuo Arai. “Design of an upper limb motion assist system with parallel mechanism.” IEEE International Conference on Robotics and Automation, 1995 pp1302-1307

[9] Carol A. Stanger, Carolyn Anglin, William S. Harwin, and Douglas P. Romilly. “Devices for assisting manipulation: A summary of user task priorities.” IEEE Transactions on Rehabilitation Engineering Vol 2(4) Dec 1994 pp256-265

[10] Stephen D. Prior, An electric wheelchair mounted robotic arm - a survey of potential users. Journal of Medical Engineering & Technology, Vol 14,n.4, pp.143-154,July/August 1990.

[11] Rahman, T., Ramanathan, R., Seliktar, R. and Harwin W. “A Simple Technique to Passively Gravity-Balance Articulated Mechanisms”, Accepted for publication in *ASME Transactions on Mechanisms Design*.

[12] William Harwin, Sean Stroud, Rungun Ramanathan, Tariq Rahman and Rami Seliktar. “Analysis and design of an arm orthosis for individuals with muscular dystrophy” P*roceedings of the RESNA Conference*. Resna Press, 1700 North Moore Street, Suite 1540, Arlington, Virginia, USA, pp. 517-519, June 1995.

[13] Lyon, P.D., Meikle, J., Montgometry, D.J., Parisi, L.A. and Rau, P.R. “Design of a gravity compensated mechanism for use in rehabilitation and robotics applications”, Senior Design Report 1994. Drexel University Mechanical Engineering Department

**Table 1: Participant demographics**

| Age | Disability |
|---|---|
| 5 | SMA-II |
| 8 | SMA-II |
| 11 | DMD |
| 13 | DMD |
| 13 | DMD |
| 14 | DMD |
| 14 | SMA-II |
| 15 | DMD |
| 18 | SMA |
| 23 | DMD |

**Table 2: Task identification results**

| C : Number of caregiver/parent responses<br>P : Number of participant responses<br>Parentheses contain the total number in that group | First meeting | | Second meeting | |
|---|---|---|---|---|
| | P(4) | C(9) | P(6) | C(8) |
| Feeding and preparing food | 1 | 6 | 3 | 3 |
| Picking up and manipulating objects from floor and shelves | | 6 | 3 | 6 |
| Transferring device to use toilet, shower etc. | | 2 | 2 | 8 |
| Brushing, combing and scratching | 3 | 7 | | |
| Reaching and picking things off shelves | 3 | | 5 | |
| Reaching beyond close range | | 7 | | |
| Keeping from falling forward, straightening oneself, maintaining balance | 1 | | 5 | |
| Straightening oneself. i.e. providing trunk support | | 1 | | 4 |
| Talking on the phone | 2 | 2 | | 1 |
| Two handed operations | 2 | 2 | | 1 |
| Typing | 1 | 4 | | |
| Opening/closing door | | 2 | 1 | 1 |
| Personal hygiene | | | 2 | 2 |
| Dressing | 1 | 1 | | 1 |
| Playing board games | | 3 | | |
| Providing full range of arm motion | | | | 3 |
| Holding/placing arm in specific position | | | | 2 |
| Operating a manual wheelchair | 1 | 1 | | |
| Playing | | 2 | | |
| Preparing food | 1 | | 1 | |
| Raising hand in school | | | 2 | |
| Straightening their own legs and ankles | | | | 2 |
| Throwing a ball | 1 | 1 | | |
| Clamping wheelchair | | | 1 | |
| Holding IPBB (respirator) machine | 1 | | | |
| Placing arm to manipulate wheelchair controls | | | 1 | |
| Playing games (baseball, hockey) | 1 | | | |
| Playing with Lego | 1 | | | |
| Turning pages | | 1 | | |