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NEW CONTROL TECHNIQUES FOR WHEELCHAIR MOBILITY

Improved wheelchair mobility could be an important factor in realizing increased independence for persons unable to walk. Motorized wheelchairs have minimized the physical strain of wheelchair propulsion, yet in many instances they do not provide adequate input control devices for certain disabled persons. Some of the conventional powered-wheelchair control concepts that are commercially available are described, along with three new types of wheelchair controller under development at APL and results from preliminary clinical evaluation of them.

INTRODUCTION

The design of contemporary wheelchairs dates back about 50 years to a lightweight, tubular-frame, folding wheelchair patented by Herbert A. Everest and Harry C. Jennings, Sr. These wheelchairs can be pushed from behind by an attendant or propelled by the user. In the latter case, the user supplies the motive forces by pushing or pulling on hand rims attached to the large rear wheels. Directional control by the user is achieved by applying hand pressure differentially to the two hand rims. Many styles and sizes of wheelchairs are commercially available. These include lightweight indoor models and heavy-duty outdoor models; sports models; and child, juvenile, and adult sizes — all with either single or bimanual drive systems. For many handicapped persons, mobility achieved by self-propulsion in such wheelchairs is an important factor in maintaining independent capability. Table 1 shows some data taken a few years ago on the number of persons in the United States with selected chronic diseases or impairments and the percentages of those persons who use wheelchairs.

Table 1

USE OF WHEELCHAIRS BY PERSONS IN HOMES FOR THE AGED AND THE CHRONICALLY ILL*

Chronic Disease or Impairment	*Number*	*Percentage Using Wheelchairs*
Diabetes mellitus	44,300	27.5
Vascular lesions	188,100	30.6
Parkinson's disease	12,500	34.5
Multiple sclerosis	3,300	77.2
Diseases of the heart	156,500	21.1
Hypertension	31,300	15.6
Arteriosclerosis	43,500	23.3
Arthritis (all types)	114,600	25.7
Rheumatism	7,700	20.3
Other diseases of the musculoskeletal system	4,800	35.8
Fracture of the femur	17,200	43.3
Paralysis or palsy due to stroke	66,600	46.2
Paralysis or palsy due to other causes	26,000	36.6
Absence of major extremities	11,600	72.6
Impairment of limbs, back, or trunk	75,200	31.8

*From National Center for Health Statistics, *Use of Special Aids in Homes for the Aged and Chronically Ill,* Series 12, No. 11 (1964).

Electric motor-powered wheelchairs were introduced about 30 years ago to provide mobility for handicapped individuals who are too weak to propel themselves. The manufacture and use of electrically driven wheelchairs were formerly discouraged by high costs, problems with maintenance and reliability, and a prevailing societal attitude that the exercise involved in self-propulsion was salubrious. In recent years, these wheelchairs have become more popular because of both the long-term survival of very severely disabled persons and a newer attitude that such persons would benefit more from applying their limited physical energy to other useful tasks than from expending it entirely on self-propulsion. A major manufacturer has estimated that the current production ratio of manually propelled to electrically propelled wheelchairs in the United States still exceeds 20 to 1. If improved control systems could be achieved, it is anticipated that a larger proportion of users would benefit from having motorized wheelchairs.

The most common control unit for motorized wheelchairs contains a two-axis joystick that is operated by the user's hand (Fig. 1). This device is simple and reliable. Although it has been reasonably satis-

Fig. 1—Standard two-axis joystick for control of powered wheelchair.

factory for many disabled persons, a substantial group remains for whom it is clearly inadequate. This group includes persons with especially poor control capability resulting from conditions such as quadriplegia, spasticity, tremors, or mental incompetence. It also includes persons desiring to operate wheelchairs in especially demanding environments (e.g., metro-train systems or hilly terrain) and desiring to operate high-speed, high-performance wheelchairs.

This paper describes some of the powered-wheelchair control concepts under development at APL that are intended to confer improved independent mobility on handicapped persons who are unable either to operate manually propelled wheelchairs or to use conventional motorized wheelchair control systems with satisfactory finesse. This research is aimed primarily at rehabilitation of persons with high-spinal-cord injuries who may have little or no voluntary control of the upper or lower limbs or of the trunk.

BASIC ELECTRICALLY POWERED WHEELCHAIR AND CONTROLLER CHARACTERISTICS

Electrically powered wheelchairs[1,2] include models originally designed for manual propulsion, to which motor-packs have been added. Primary power is usually derived from one or two automobile-type lead acid batteries that energize friction drive, belt drive, or direct drive motors coupled to the drive wheels of the wheelchair. The power components add 40 to 120 pounds of additional weight to the base weight of a manually powered wheelchair. Disadvantages of a powered chair are its additional weight and bulk and the associated difficulties encountered in lifting it and placing it in an automobile. A powered chair cannot easily be taken up or down stairs even if the patient is first removed from it. On moderately smooth terrain, an electric wheelchair can travel about 15 miles on a single charge. Maximum speed is dependent on the motor package and can be up to 5 miles per hour for standard wheelchairs. Some wheelchairs are of a high-performance type and reach speeds of 7 miles per hour.[3] Approximately 12,000 battery-powered wheelchairs are manufactured annually in the United States. Although many improvements have been made in their design during the past few years, high initial cost and frequent failures still cause some potential users to continue using manually propelled models.

Several types of wheelchair control input devices are now commercially available.[2] These include an arm-rest-mounted, hand-operated joystick; a chin-, mouth-, or head-operated joystick; a sip and puff (pneumatic) controller; and a tongue-operated switch controller. Frequently, microswitches and circuit breakers are connected to the motor for two-speed, on-off control. In the last few years, proportional electronic controllers have become available. These new systems provide smoother control than do the ones with microswitches.

CHIN CONTROLLER

The first type of powered wheelchair controller that has received consideration in the research and evaluation program at APL is one intended for persons with high-spinal-cord injuries. To control his wheelchair, such a person must use some signal derived from his head; one conventional type of wheelchair controller for him is shown in Fig. 2. This is the Veterans Administration Rehabilitation Engineering Center (formerly the VA Prosthetics Center) chin controller. It contains a modified joystick that is positioned for operation by motion of the chin. Moving the chin up and forward controls forward speed, moving it left or right controls turning, and moving the controller down and backward controls reverse speed. Although under ideal circumstances this device allows reasonable control of a wheelchair, its bulk and location in front of the face are objectionable. The location of the control box also restricts or prevents use of a mouthstick. Because a mouthstick is a very useful manipulative tool for many high-level quadriplegics, this feature of the controller is a significant disadvantage.

The APL design[4] for a chin controller[5] is shown in Fig. 3. The control box has been miniaturized and relocated on the back of the wheelchair behind the user's head and neck. An inconspicuous tubular extension curves around one side of the neck and terminates just below and in front of the chin. Downward motions of the chin depress this lever, thereby controlling wheelchair velocity. Lateral movements of the lever provide directional control. A microswitch at the tip of the chin lever permits selection of the reverse mode. An electronic interlock circuit inhibits operation of this reverse switch except when the wheelchair is at rest.

Fig. 2—VA chin controller for a powered wheelchair.

The two axes of chin motion are measured by two optical angular transducers located in the control box, as shown in Fig. 4. This method of angular measurement is chosen for its inherent reliability and low cost. The usual industrial use of these particular transducers is for identification of coded lines on computer cards in high-speed sorting machines. Each transducer costs approximately $2.50.

When the user has no need for mobility control, he can easily push the controller aside with his chin, thereby clearing the area in front of his face for use of a mouthstick. Whenever he desires, he can retrieve the controller by chin motion alone. This new chin controller is cosmetically inconspicuous in either position. A chin controller system of this type has been designed at APL that is electrically and physically compatible with the Everest and Jennings (E&J) Model 3P Electric Wheelchair.

A unique and innovative feature of the APL chin controller is closed-loop velocity control. (Its technical details are described in a subsequent section of this paper.) One of the advantages of this feature is its ability to set velocity limits that are consistent with each patient's particular ability to control his own wheelchair. Another advantage is self-braking downhill, an especially important safety factor on slopes and irregular terrain. Another important characteristic is electronic filtering in the speed control loop. This eliminates unwanted velocity perturbations caused by head motions that may occur when negotiating bumps and rough terrain. Electronic filtering is especially desirable for quadriplegics who lack good trunk stability. The filter does not affect steering response.

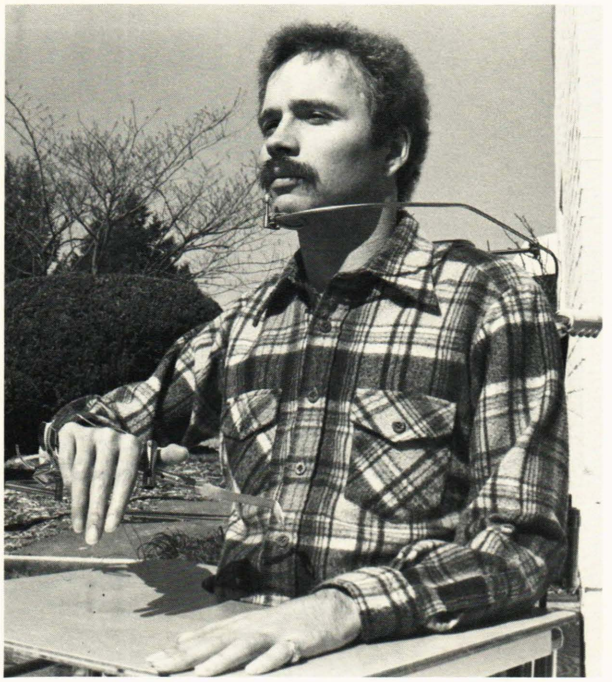

Fig. 3—Low-profile chin controller designed at APL.

The APL chin controller has been fitted to five E&J Model 3P powered wheelchairs for clinical evaluation by quadriplegic volunteers. A typical wheelchair fitted with the controller is shown in Fig. 5. These tests have been in progress over the past two years.

The APL chin control design has completed a successful clinical evaluation and is now being offered to manufacturers. We hope that it will reach the marketplace at an early date in order to benefit handicapped individuals currently in need of such devices.

CLOSED-LOOP VELOCITY CONTROL

Improved wheelchair controllers were acknowledged as one of the important needs of the handicapped during a major conference on wheelchairs sponsored by the VA and by the Rehabilitation Services Administration in December 1978.[6] Improved controllability; less sensitivity to involuntary motions, spasticity, and tremors; and more safety features were noted as some of the parameters needing additional refinement.

During 1978, the principle of closed-loop velocity control was applied by APL to both the chin controller and the hand-operated joystick controller. Closed-loop feedback is achieved by adding a tachometer to measure the output at each motor shaft

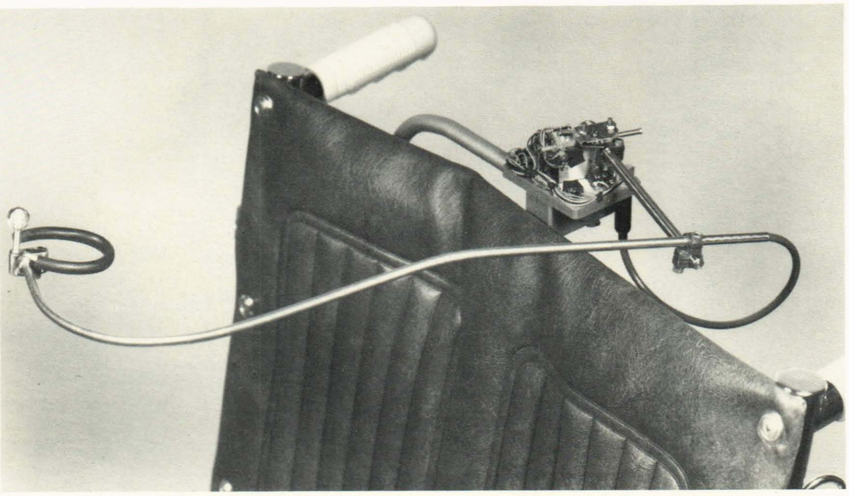

Fig. 4—Transducer measurement unit for low-profile chin controller.

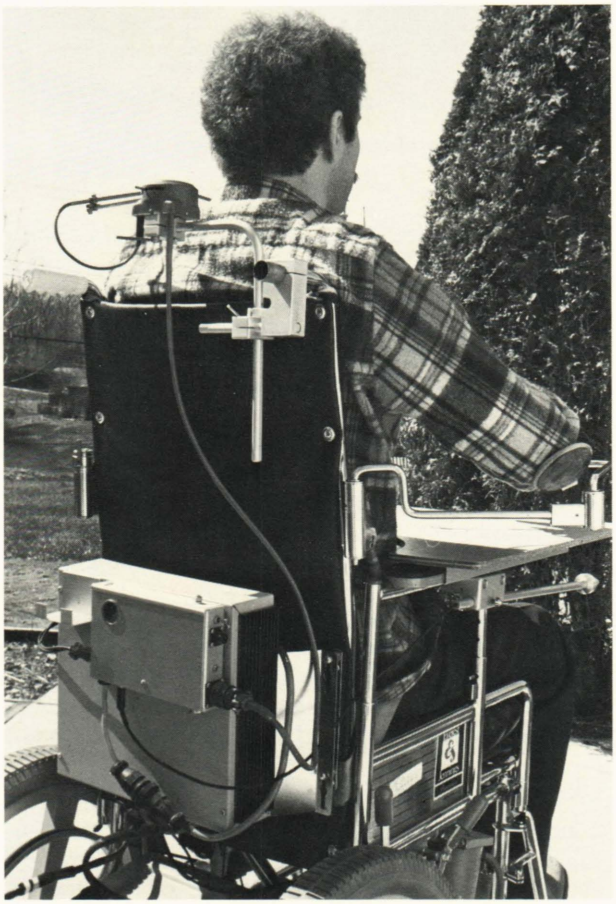

Fig. 5—Component mounting arrangement for low-profile chin controller.

and by adding a small amount of electronic circuitry. The joystick input motion or the chin-controller input motion thus becomes a velocity command signal rather than a torque command signal. This allows the user to control his velocity directly, without consideration either for the increased resistance to motion imposed by rough terrain surfaces and ascending grades (up to the upper limits of the power system) or for the decreased resistance to motion allowed by smooth terrain surfaces and descending grades. The latter feature is especially desirable because it automatically retards the wheelchair whenever the operator releases the control lever or does not position it to command full speed ahead.

Closed-loop velocity control also permits adjustable electronic limiting of forward or reverse velocity without reducing available motor torque. This is an especially desirable feature for indoor operation of a motorized wheelchair by a person with marginal control capability. He can thereby achieve full torque at low velocity (for example, to overcome the resistance of a door threshold or to turn on a thick rug) without incurring an abrupt increase in velocity as soon as the obstacle has been overcome and without changing his control input. Due to the usual problems of detecting and avoiding obstacles when backing up, limitation of reverse velocity is also an important safety feature of the system.

Two joystick-operated wheelchairs modified for closed-loop control have been tested in residential and industrial environments by volunteers over a period of several weeks. One volunteer had good hand control but limited strength and endurance caused by Friedreich's ataxia. For comparison, she first used a wheelchair equipped with a conventional open-loop joystick control system for three days in her home for 6 to 8 hours per day. For the next 15 days, she used a wheelchair equipped with the APL closed-loop velocity control joystick for about 6 to 8 hours per day. She reported that the open-loop-controlled wheelchair was much more difficult to maneuver in tight spaces without striking objects and especially when attempting to maneuver on carpets and rugs at low speeds. With the closed-loop, velocity-controlled wheelchair, this volunteer encountered less difficulty with directional control when ascending ramps and in avoiding overspeed when descending. She perceived that operation of the wheelchair equipped with the closed-loop velocity control required less conscious mental effort. She also stated that she would like to obtain such a wheelchair controller when it becomes available commercially.

The other volunteer was a high-level quadriplegic veteran who had achieved very marginal capability with a manual joystick. His wheelchair was equipped with both torque control and closed-loop velocity control modes, a selector switch, and a choice of high or low speed limits. At the end of the test period it was concluded that his degree of muscle weakness interfered with his ability to position the joystick adequately for fine control with either open- or closed-loop control modes. He could not take advantage of the special features of the closed-loop controller indoors, but found it superior outdoors, particularly on irregular terrain.

Electronic damping can reduce the sensitivity of a manual or a chin-operated controller to a variety of undesirable inputs due to high-frequency tremors, spasticity, or abrupt movements or oscillations induced by running over bumps. This can be achieved most effectively by filtering in the speed control loop. Although significant clinical testing has not yet been conducted, it is anticipated that the closed-loop controller with this filtering may be especially useful for some patients with cerebral palsy.

One manufacturer has expressed interest in manufacturing this controller as an interchangeable module for joystick-operated E&J Model 3P wheelchairs. Limited testing of prototypes manufactured by that firm is planned in preparation for wider field testing prior to introducing the item to the marketplace.

POWERED ASSIST WHEELCHAIR

During 1977, a third type of wheelchair controller was conceived[7] and developed at APL. This model utilizes input to the wheel rim similar to that involved in hand-propelling a conventional wheelchair; however, powered assist is provided to minimize the effort of self-propulsion. Powered assist is achieved by decoupling the hand rims from the drive wheels so that they can rotate independently and, by using the electric motors, cause the drive wheel to rotate at the same speed as the hand rim. Transducers are introduced to measure the velocity of hand rim rotation and to relate this velocity to that of drive wheel rotation on the same side. The design concept is similar to that of automotive power steering.

This control mode for the motorized wheelchair may improve maneuverability within small spaces, especially for persons previously accustomed to hand-propelled wheelchairs and who no longer have enough strength and endurance for self-propulsion. Two demonstration models of this concept (one model is shown in Fig. 6) have undergone limited testing indoors and outdoors at APL. A volunteer used one of these models to compare its performance to that of her own manually propelled wheelchair. She suffered from Friedreich's ataxia and participated in the closed-loop wheelchair testing described earlier in this report. She felt that the powered assist wheelchair increased her range and maneuverability to the extent of enabling her to perform specific tasks otherwise beyond her capability. An example cited was the ability to maneuver through a grocery store and fill her shopping cart without assistance or exhaustion.

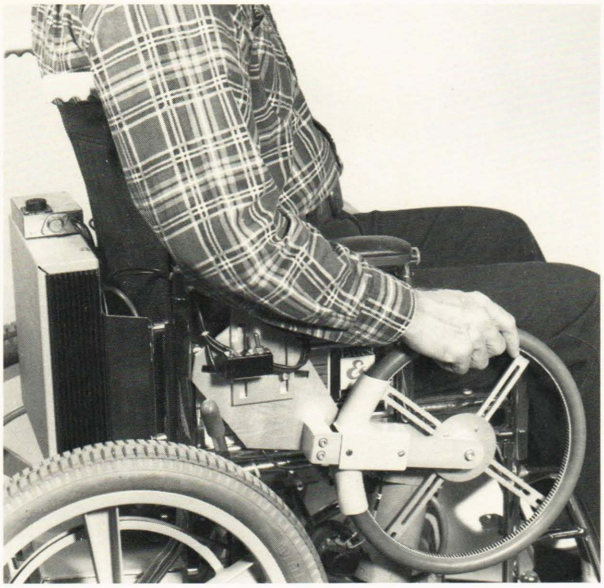

Fig. 6—Hand-rim controlled powered wheelchair. The drive wheel follows the hand rim's motion for precision and ease of control. Negligible force is required for wheelchair motion.

Evaluation Results

- C. R., a 32-year-old veteran with spinal stenosis, resulting in quadriplegia eight years ago, is now living in a State hospital and commutes daily by van to a community college. He received his test wheelchair and control system in early January 1980. He is active in it all day and evening. C. R. used the wheelchair controller for approximately six weeks, in combination with the APL robotic/arm worktable system, in an evaluation of its patient self-feeding potential.[8] After testing the wheelchair for over one year, he continues to prefer this controller to his conventional VA Prosthetics Center controller.

- M. S., a 23-year-old veteran injured three years ago, is now living in a suburban nursing home. The test control system was attached to his existing wheelchair in early April 1980. With the system, M. S. continues to be actively mobile in his wheelchair in the mornings. He is confined to bed in the afternoons.

- B. J. is a 19-year-old injured three years ago. He received his test wheelchair controller in January 1979. Use of the wheelchair has made it possible for him to complete high school and to continue his college education in Denver. Although minor mechanical repairs have been required every several months, he has been very satisfied with the system and is anxious to retain it.

- M. C., a 36-year-old injured 17 years ago, received a test wheelchair and controller in April 1979. He was active in it, usually all day and evening, until a month ago when he was obliged to move into a house without ramps. Prior to obtaining his electric wheelchair, and since moving into less advantageous housing, M. C. has required an attendant to push him in a manual wheelchair whenever he desires to move about. The electric wheelchair gave him a new sense of independence while permitting him to continue using his mouthstick for page-turning and typewriter activities. He hopes to return to his electric wheelchair as soon as ramps are completed in his current residence.

- D. W. is a 33-year-old man injured three years ago. He is a quadriplegic with no significant voluntary muscle power below his shoulders. He was fitted with a wheelchair controller in November 1980. D. W. is presently evaluating an integrated robotic/arm worktable system[9] that is directly operable from his wheelchair chin controller via an infrared coupling link from the wheelchair to the worktable. These tests are continuing.

- J. C. is a 43-year-old injured 10 years ago. He currently lives in a rural nursing home. He received two different early models of the test wheelchair and control system about three years ago. He is active in his wheelchair for only a few hours at a time on an infrequent basis.

With the exception of J.C., who spends substantially more time in bed than the others, all of these quadriplegics have been using the APL chin controller on a daily basis, are enthusiastic about its performance, and have experienced no significant failures.

CONCLUSIONS AND FUTURE PLANS

Motorized wheelchairs provide mobility for a substantial number of disabled persons who are too weak to hand-propel themselves in nonpowered wheelchairs. This mobility greatly enhances the potential of such people for self-fulfillment. However, the design of currently available control systems greatly limits the user's ability to maneuver motorized wheelchairs easily within confined spaces or to ascend and descend inclines and surmount minor obstacles without abrupt changes in velocity. Operation of available control systems requires a level of dexterity that many potential users lack. Improvements in motorized wheelchair control systems can extend the significant benefits of independent mobility to a large number of handicapped persons, especially those with high-spinal-cord injuries.

The JHU/APL controllers described in this article illustrate a new generation of motorized wheelchair control techniques. The chin controller is especially useful for persons with no upper limb function. It is cosmetically inconspicuous and fully compatible with mouthstick use. The closed-loop velocity control principle, which has been incorporated into both the new chin controllers and the manual joystick controllers, contributes to smooth operation over obstacles, safety on inclines, and precision maneuvering. It is anticipated that some of these design concepts will be manufacturable within the next few years and that future control systems incorporating microprocessors will enable wheelchair performance to be programmed to fit each user's need more appropriately.

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