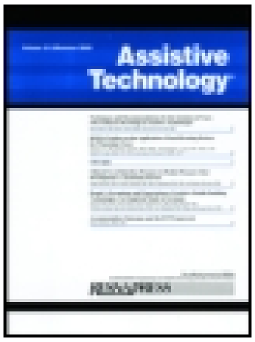

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Integrating the control of accessory devices into a wheelchair joystick can both optimize function and improve aesthetics. Although the number of commercial systems having this feature is increasing, there is still a number of joystick controllers in the field that do not provide integrated accessory device control. This paper describes the design of an add-on system that allows the user to control both the wheelchair and accessory functions using a proportional joystick controller. The mode of operation is chosen with an external switch that can be mounted at any desired location. Accessory control can include both wheelchair functions, such as power recline, and external functions, such as an environmental control unit. The design is especially well suited as a retrofit to existing wheelchair control systems. A case report of an individual with quadriplegia is presented demonstrating a successful implementation of this system.

Key Words: Proportional joystick—Joystick modification—Accessory control—Wheelchair control—Wheelchair switch options—Wheelchair switch output.

Individuals with high-level quadriplegia with residual upper-extremity function can often learn to control proportional hand joysticks. However, they may not be able to operate standard controls for other wheelchair-based systems, such as the power recline or an environmental control unit (ECU). The best solution to this problem is to integrate control of all of these functions into a single user interface, i.e., the joystick. Until very recently, commercial proportional hand joysticks incorporating alternative switch outputs have not been readily available. As availability of these increases, the need for joystick modification to incorporate accessory control on new wheelchair controllers should be minimized. However, the concept remains useful as a retrofit for many existing wheelchair systems and those new ones that do not offer accessory control options.

This paper describes the design of an add-on system that integrates the control of a number of switch outputs for accessory devices into a proportional joystick. A case report of an 18-year-old man with quadriplegia is presented to illustrate such a solution.

RATIONALE

Commercial systems with integral wheelchair and accessory switch control have been available for a number of years. However, these have been limited to a proportional chin joystick and various switch-based control systems. Both of these methods have significant disadvantages in comparison to proportional hand joystick systems. First, switch-based control systems do not offer the same level of control as a proportional control system, because adjustments to the speed and direction of the wheelchair are made in discrete discontinuous steps. The user may be limited to commanding the wheelchair to move directly forward, right, left, backward, and to

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increase speed. These limitations are especially problematic in close quarters and on rough terrain. An additional limitation of pneumatic breath-operated systems is that the sequence of sips and puffs required for operation is not intuitive, and new users require instruction from a clinician for even basic movements.

In contrast to switch-based systems, proportional systems provide continuous adjustment of speed and direction. The wheelchair moves in the direction in which the joystick is deflected and at a speed directly proportional to its displacement. While proportional chin joysticks are available for people with limited upper-extremity function, many people find proportional chin joystick systems cosmetically unappealing, and they limit head and neck movement while operating the wheelchair. Chin joystick systems do not encourage upper-extremity activity that may be important for strengthening the involved extremity. Thus, a proportional hand joystick system is generally preferred for driving a wheelchair.

In order to operate accessory devices, a number of switch outputs must be available. This is independent of the type of control system that is used. For individuals with good upper-extremity function, this is not an insurmountable problem, since a number of standard switches can be mounted in proximity to the joystick. However, it may not be possible for someone with marginal control for driving to remove his hand from the joystick in order to operate accessory switches. Switches may be mounted at other sites, such as over each shoulder or on the headrest, but like a chin joystick these can limit the user's freedom of movement and can be aesthetically unappealing. Generally, it is most desirable to incorporate additional switch outputs into the proportional hand joystick.

METHODS

In the custom system that was developed, four switch outputs were added to a commercial proportional hand joystick. A block diagram of the system is shown in Fig. 1, and an electronic schematic is shown in Fig. 2. Briefly, the system consists of four components added to the wheelchair: (a) a switch to cycle through the three operational modes, (b) the additions to the joystick, (c) the control electronics, and (d) a mode display unit mountable anywhere on the chair. Details of these components are described below.

The system incorporates three operational states: (a) a **drive** mode, (b) an **accessory** mode, and (c) an **off** mode. A momentary single pole switch is used to sequence between each of these three modes. This "mode" switch can be activated by the head or any

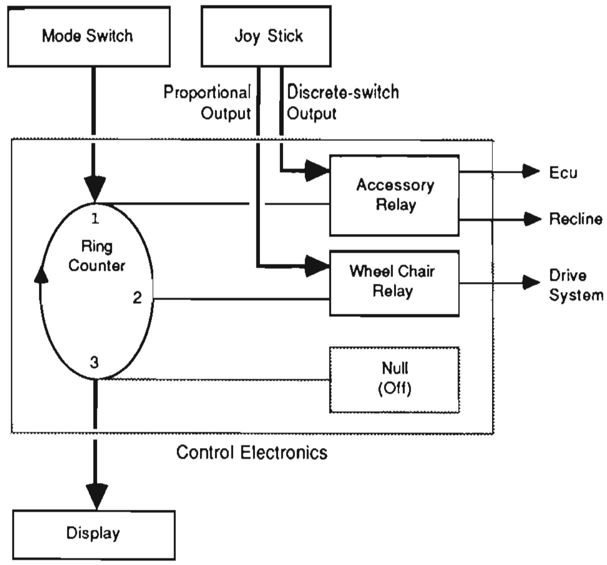

FIG. 1. Block diagram of accessory switch control.

other functional motion. When the system is in **drive** mode, the proportional joystick output is connected through a relay[1] (Magnecraft W171DIP-27) to the standard wheelchair controller, and the accessory switch outputs are disabled. In this mode, the movement of the joystick produces proportional output for driving the chair. Since the joystick is connected to the chair in the standard manner, the entire add-on system is invisible to the wheelchair controller.

An important safety consideration is that the mode immediately following **drive** is always one in which all outputs are disabled so that the mode switch functions as a "kill" switch. This is particularly important when hand splints are used and the individual may be mechanically tied to the joystick. Therefore, activation of the mode switch while in **drive** steps the sys-

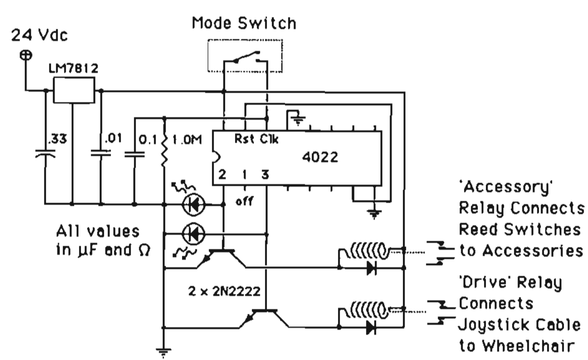

FIG. 2. Electronic schematic of control circuitry.

[1] Newark Electronics, 4801 N. Ravenswood Avenue, Chicago, IL 60640-4496.

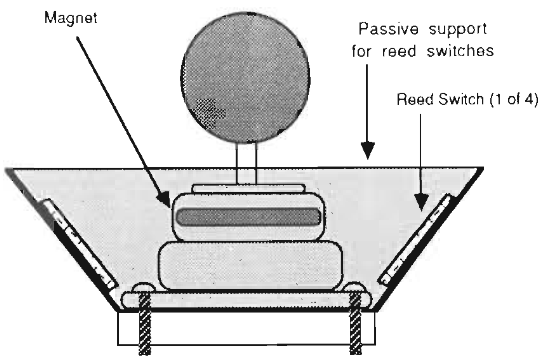

FIG. 3. Reed switches and housing mounted on joystick.

tem to **off**, in which movement of the joystick has no effect and power to the wheelchair is disconnected.

From the **off** mode, activating the mode switch again advances the system to **accessory** mode. Wheelchair power is automatically disconnected in **accessory** mode. In this state, displacement of the joystick actuates one of an array of four switches, and these outputs are coupled to the accessories through a second relay.[1] For example, forward and reverse movements can be used to control a power recline, whereas left and right may be coupled to an ECU.

The additions to the joystick in this design involved an external system to detect the mechanical displacement of the stick. A toroidal magnet[2] was mounted on the axis of a joystick within a protective rubber bellows. Four magnetic reed switches[1] were positioned in a square plastic cup surrounding the bellows. The cup was initially prototyped with a soft sheet of aluminum, and, once the angles and locations of the walls were determined, plastic was vacuum-formed over a wooden mold. Figure 3 is a diagram of the modified joystick.

The activation of the reed switches depends on the interaction between the switches and the toroidal magnet. Reed switches are slender glass tubes with two ferromagnetic reeds positioned axially and overlapping in the middle. They are activated by a magnetic field of the proper strength and alignment. Therefore, when the joystick is moved far enough in an appropriate direction, the toroidal magnet is close enough to one of the reed switches to activate it.

Reed switches were chosen because they have some advantages over mechanical switches; specifically, they are very small, quiet, and durable and require no mechanical linkage for operation. They are, however, brittle and have a limited spatial range of sensitivity, and so require some care during installation. They must be positioned so that they trigger before the joystick is at full displacement and so that they open again when the joystick is in neutral.

The electronics which control the system are based on a 4022 CMOS ring counter.[3] Incoming pulses from the mode switch are conditioned with an RC network and passed on to the clock input of the counter. Each pulse steps it once, sequentially turning the next output on. On every third step, the output is routed into the reset pin and the counter recycles. Two of the counter outputs are coupled to the display indicator lights and through driving transistors to a pair of relays. The lights provide feedback for the user regarding the current mode. The relays selectively pass or prohibit signals and power to and from the reed switches and the proportional joystick. With this design, the number of modes can easily be increased to include up to eight **accessory** states by reprogramming the ring counter and using a larger number of output relays.

CASE REPORT

An 18-year-old man sustained a C5-6 spinal subluxation in a motor vehicle accident and was immediately admitted to a neurosurgical intensive care unit. Over the next several days, his paralysis ascended to the C1-2 level leaving him ventilator-dependent. An emergency laminectomy with myelotomy was subsequently performed. He gradually regained partial neurologic function to the C5 level, which led to improved left upper-extremity function over a 1-year period. With this improvement and the aid of a wrist splint, he was able to operate a hand joystick for control of a power wheelchair.

His requirements included a power wheelchair recline system that allowed independent movement to compensate for hypotension and provide pressure relief. He also needed access to an environmental control system from his wheelchair in order to operate a telephone, room lights, television, and a number of other devices.

The number of commercially available wheelchair/environmental control systems suited to this patient's needs was limited. One important criterion was that appropriate dealer support for maintenance and repair be readily available due to the patient's dependence on his mobility and environmental control systems. It was also desirable to make as much use of his functional abilities as possible and provide him with a hand joystick control.

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[2]Radio Shack, Division of Tandy Corporation, Fort Worth, TX 76102.

[3]Digi-Key Corporation, 701 Brooks Avenue South, P.O. Box 677, Thief River Falls, MN 56701-0677.

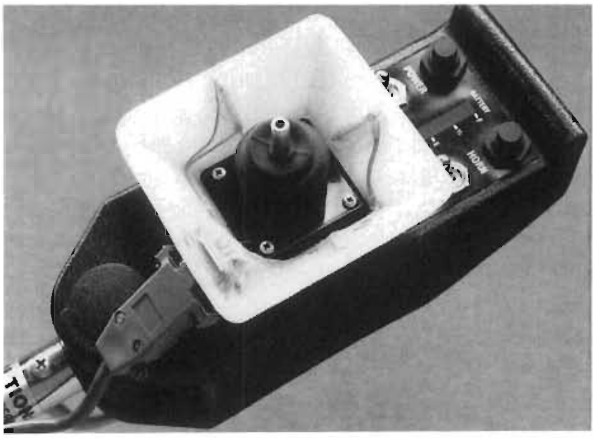

FIG. 4. Actual system mounted on proportional joystick controller.

Given these criteria, there were two available options. One was a switch-controlled joystick with the required accessory switch outputs such as those available using Invacare's Switch Options[4] or the Duomode Simplex Control system from Dufco Electronics.[5] The second was the proportional chin joystick controller with accessory switch output, found in the DU-IT DLT system.[6] At the time of the evaluation, there was no local dealer support for other systems, such as the Permobil[7] wheelchairs, which offer switch options through a proportional hand joystick. Additionally, the MCC Controller, the newest Invacare control system,[4] which also incorporates switch control into a hand joystick controller, was not yet available.

Disadvantages to both the switch hand joystick and the proportional chin joystick systems were discussed above. The particular proportional chin joystick control system identified had the added disadvantage of being offered with a chair that doesn't provide "quiet" operation (elimination of the electronic whine from motor control) or regenerative braking found on many power wheelchair systems. Experience with the reliability of the various systems was also an important consideration in the evaluation. The result of the evaluation was the prescription of an Invacare Rolls Arrow,[4] including the standard proportional hand joystick, with the modification of the joystick control as described to provide switch outputs for control of power recline and other environmental functions. The actual system mounted on the joystick controller is shown in Fig. 4.

[4]Invacare Corporation, 899 Cleveland Street, Elyria, OH 44036.

[5]Dufco Electronics, Inc., 2410 Broad Street, San Luis Obispo, CA 93401.

[6]DU-IT Control Systems Group, Inc., 8765 Twp. Road 513, Shreve, OH 44676-9421.

[7]Permobil of America, 1403 Massachusetts Avenue, Lexington, MA 02173.

DISCUSSION

The augmented joystick system design was a successful solution to a specific problem. It blended cosmetically and functionally into the rest of the power mobility system and has worked well for the client since its delivery approximately 1 year ago. However, there are a number of ways to design an equivalent joystick modification, and two of these are discussed below.

First, our design required the addition of four reed switches to provide the accessory switch outputs. Another possibility, however, is to interface with the existing wheelchair control system, i.e., to tap the analog voltages resulting from left–right and fore–aft stick motion. In this manner, thresholds can be set electronically and used to activate any number of discrete switch outputs. This approach is most desirable from a manufacturer's point of view as an incorporated option, but, as an after-market modification, it requires extensive technical knowledge of the electronic design and functioning of the particular chair controller. It would require disassembly and invasive modifications and would void the warranty. For these reasons, we did not choose to employ this technique in our system.

One major design change that is recommended for any future versions of this system is to attach the accessory switch array superficially to the joystick enclosure. This would help preserve the manufacturer's warranty, since the joystick enclosure would not have to be opened, even for mounting purposes. In addition, mounting the switch array to the top of the enclosure would make it more easily adaptable to a variety of joystick models.

One proposed way to implement this design is to mount a dome with a square opaque brim so that it slides within four guides when the joystick is displaced. An optical source and sensor[1,3] could be embedded within each of the sliding dome guides. Thus, when the joystick is pushed far enough in one direction, the brim of the dome occludes the internal light beam, thereby triggering a relay. This requires the addition of four additional relays but would comprise a more durable mechanical design and one that would be applicable to a broad range of joystick geometries. This design is also completely external and would not require the installation of a magnet. Figure 5 depicts the mechanics of a system utilizing optical sensors.

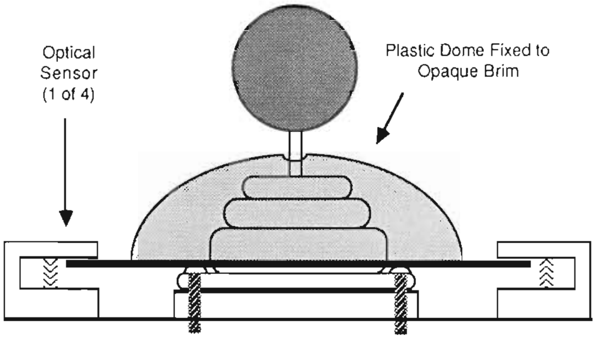

FIG. 5. Proposed optical accessory switch design. The dome/brim is free to slide in two dimensions.

CONCLUSIONS

Hand joystick controls with integrated switch outputs for accessory control are becoming more readily available on the market. This eliminates the need to perform custom adaptations for many new systems. On the other hand, the need remains for a simple system that can be retrofitted to earlier model controllers and current models that do not offer accessory switch control options. The least expensive of the commercial systems now available that can combine proportional driving control and accessory switch outputs costs $1,700 for the electronics required for switch outputs, in addition to the cost of the circuitry required to drive the wheelchair motors. While it is difficult to estimate the value of the time that has been devoted to the developmental work described in this paper, all of the materials required cost approximately $200, and fabrication of a second reed switch-based unit could be completed within 2 days. Therefore, this design could be replicated for $200–1,000, depending on labor costs. Although the decision to prescribe a custom system should be made carefully, the described custom adaptation has proven to be reliable and cost-effective. It provides a practical and economical approach to incorporating switch controls for accessories into a standard joystick.

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