A GENERAL PURPOSE ELECTROMECHANICAL SIMULATOR FOR SWITCHES USED IN THE REHABILITATION OF COMMUNICATION-IMPAIRED PEOPLE

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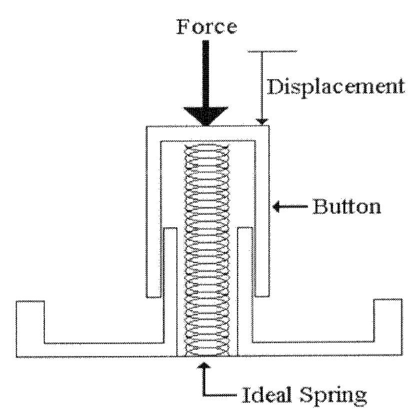
Summary The importance of simple mechanical switches in rehabilitation cannot be overstated, particularly in the facilitation of communication and control by people with profound physical disabilities. Many communication and control systems are designed to be operable using a single switch (or a small number of switches). A crucial step in the tailoring of a system to a patient who will operate it in this way is the selection of an appropriate switch, according to their physical abilities. We present a prototype switch simulator, capable of reproducing various types of switching action under computer control. This electromechanical device exhibits a force versus displacement characteristic (possibly incorporating hysteresis) selected by the user on the PC. In this way, the suitability of a variety of switching actions for a patient can be assessed, and the optimal choice identified. Furthermore, for patients with very particular needs, this device can implement switching actions which are difficult or impossible to reproduce in a passive mechanical switch. For example, a patient may be able to close a thumb-operated switch but not be able to withdraw their thumb to open the switch again. Using the switch simulator, an exaggerated restorative force can be applied once the switch has been closed and until it returns to the fully open position.

1. INTRODUCTION

Paralysis or other serious impairments of motor function can arise as the result of a variety of causes, including stroke, spinal injury, head injury or any of a number of other neurological conditions. Through the application of appropriate assistive technology, a degree of independence can be restored to a person that might otherwise be reliant on his or her carers for almost every interaction with their environment. In particular, a wide range of systems designed to facilitate communication, environmental control and computer use for users with disabilities are commercially available. Many such systems are designed to be operable using a single switch (or a small number of switches). The specific switch or switches used to interface with a given device or system may vary from user to user according to their differing abilities. Popular switches include hand switches, head switches, chin switches and suck and blow switches. Some switches require no actual bodily contact, instead being actuated by sound (either verbal [3] or non-verbal [4]), or by gestures recognised visually using image processing techniques [5,6]. Certain systems designed for the most profoundly physically disabled users do not detect body movements at all, being activated instead by voluntary modification of the electroencephalogram [7,8].

In fact, any device capable of translating a user's intent, by whatever means, into a signal capable of controlling a device may be thought of as a switch. However, even in cases of profound physical disability, while any vestigial voluntary body movement remains, a simple mechanical switch often represents the most robust solution. The choice of a switch with mechanical properties suitable for the intended user is an essential first step in the successful provision of a switch-controlled system.



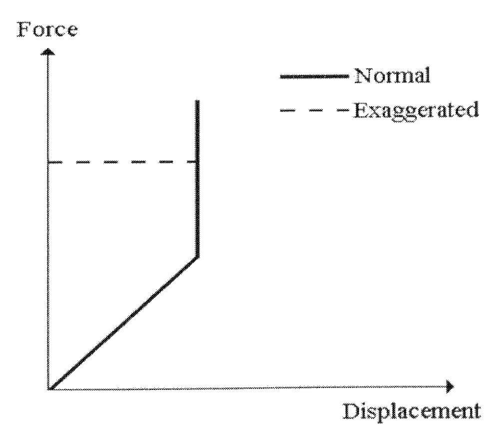


Figure 1 The force-displacement characteristic associated with an ideal spring-mounted button. Also shown is an example of an exaggerated restorative force, possible only with an active device.

The prototype device described in this paper aims to facilitate this assessment process by simulating, under computer control, various switching actions.

2. THEORY

Typically, mechanical switches used in rehabilitation engineering are of the push-to-make variety, having two terminals that are open-circuit until a force exerted by the user closes the switch, short-circuiting the terminals. Most such switches have a single degree of freedom, and can usefully be characterised by one or more connected curves on the force-displacement plane.

A curve in the force-displacement plane associated with a particular switch records the minimum force required at each value of displacement to move the switch mechanism in the direction of greater displacement. Neglecting the effect of friction, application of any force less than this will result in the switch displacement decreasing. In other words, taking the example of a spring mounted push-button switch, if the user does not exert enough force to overcome the spring force, the button will begin to rise up. For illustrative purposes, the force-displacement characteristic associated with an ideal spring-mounted button switch is shown in Fig. 1. Also shown in the diagram is the force-displacement characteristic associated with an exaggerated restorative force. This second characteristic comes into effect only during the time between closure of the switch and the switch returning to its rest position. Such behaviour is not possible to achieve with a passive device, but can be incorporated into a simulated switch action using an active electromechanical device.

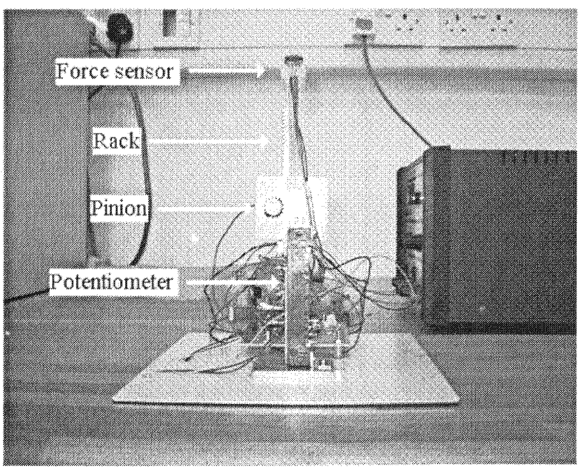


Fig. 2. The prototype with its cover removed to show the force sensor, rack, pinion and potentiometer.

2. DESIGN OF PROTOTYPE

The prototype consists of a push-button, mounted on top of a movable steel shaft, which slides up and down in a stationary chassis. Assuming that the chassis is resting on a level surface, the shaft can move only in the vertical direction. In order for the controlling computer to simulate various switching actions via the mechanism, both the force applied by the user and the displacement of the shaft must be monitored constantly and an appropriate force exerted on the shaft electromechanically. The prototype is shown in Fig. 2 with its cover removed.

Attached to the chassis is a 70mm, 50kΩ sliding potentiometer, the sliding contact of which is connected to the moving shaft. A constant voltage of 5V is applied between the ends of the resistive track of the potentiometer. The displacement of the shaft relative to a reference position can therefore be inferred from the voltage measured at the sliding contact of the potentiometer. This voltage varies, as a linear function of displacement, from 0V when the shaft is at the upper limit of its range of movement to 5V when at its lower limit.

A Honeywell FSG15N1A force sensor is mounted on the top of the shaft, allowing the force applied by the user to be measured.

The controlling computer acquires the measurement signals from the force sensor and potentiometer via a National Instruments PCI 6023-E data acquisition (DAQ) card. To reduce the effect of quantisation noise, the differential output of the force sensor is amplified and converted to single-ended form prior to analog-to-digital conversion.

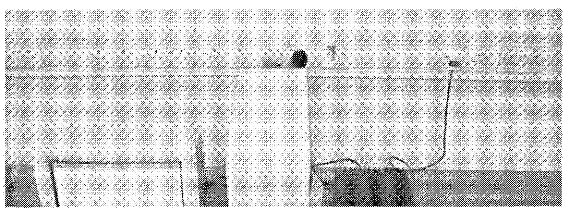
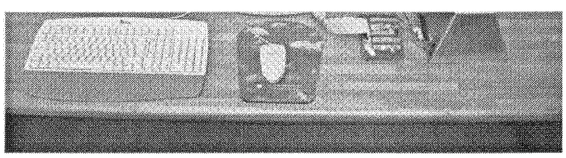


Fig. 3. The complete prototype system.



A Radionics 255-9611 bipolar DC electric motor attached to the chassis exerts a variable force on the shaft via a rack and pinion assembly. The computer controls the voltage applied across the terminal of the motor, and hence the force applied to the shaft, via an 8-bit parallel digital output provided by the DAQ card. This digital signal feeds an Analog Devices AD577 D/A converter, the output of which is connected to a power amplifier, which delivers a voltage between +12V and -12V to the motor.

The software used to analyse the force and displacement data and generate a suitable control signal in real-time is Simulink Real-Time Workshop. This tool facilitates rapid prototyping and, in this application, permits the control scheme used to determine the behaviour of the switch to be modified painlessly.

Finally, when the simulated switch is deemed to be closed, as determined by the displacement of the shaft, a reed relay is activated by way of a single output pin on the computer's parallel port. This allows the prototype switch simulator to be used to control an existing switch-operated device or system. The complete prototype system is shown in Fig. 3.

4. TESTING

Initial user trials using able-bodied subjects were carried out. The prototype was connected to an existing switch-operated communication system, comprised of a laptop computer running an alphabet board program, equipped with a USB switch interface module. The alphabet board software allows messages to be spelled out one letter at a time using a single switch. The letters of the alphabet are displayed in a grid formation. Each row of the grid is highlighted in turn. When the row containing the desired letter is highlighted, the user presses the switch. Each letter in that row is then highlighted in turn. When the desired letter is highlighted, the user presses the switch again to select it. Subjects were asked to spell short messages using the switch simulator as the input device. The level of difficulty associated with switch activation was observed to be clearly dependent on the control scheme selected on the computer.

5. CONCLUSION

The results of initial user trials were promising, indicating that the prototype device could clearly be used as an input device for a switch operated communication or control device. However, certain mechanical limitations of the device prevent the current design from reproducing the very subtle switching actions required by some profoundly disabled users who can exert forces of only very small magnitude, and only over a tiny range of movement (e.g. less than 5mm). In particular, momentum associated with the internal gearing mechanism of the motor unit prevented very rapid acceleration or deceleration of the shaft. Nevertheless, even in its current form the switch simulator provides a valuable function that no passive switch can – its capability of producing an exaggerated restorative force to return the switch to the "open" position, ready to be pressed again by the user. This solves a very real problem experienced by certain users who may be able to move a body part, such as a thumb, in one direction to close a switch, but not in the other to release it again.

Furthermore, the apparatus described here records much more information than simply whether or not the switch was pressed. Although no attempt has yet been made to do so, appropriate analysis of this additional data could allow involuntary movements due, for example, to muscle spasms to be distinguished from voluntary switch activation and hence ignored.

Although the apparatus described here is somewhat unwieldy and has been used only as a push-button switch sitting on a table top, it is worth mentioning that it could easily be connected by mechanical means, such as a push-pull cable in a tubular conduit, to a lightweight device such as a hand-held actuator. Also, since this prototype is intended solely for experimental work, the need for a computer to control the prototype is quite acceptable. However, once the ideal switching action for a particular user has been identified, it is envisaged that a microcontroller could automatically be programmed to control the simulator apparatus independently of the computer, reproducing the same behaviour.

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