Application of Tilt Sensors in Human–Computer Mouse Interface for People With Disabilities

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***Abstract*—This study describes the motivation and the design considerations of an economical head-operated computer mouse. In addition, it focuses on the invention of a head-operated computer mouse that employs two tilt sensors placed in the headset to determine head position and to function as simple head-operated computer mouse. One tilt sensor detects the lateral head-motion to drive the left/right displacement of the mouse. The other one detects the head's vertical motion to move up and down with respect to the displacement of the mouse. A touch switch device was designed to contact gently with operator's cheek. Operator may puff his cheek to trigger the device to perform single click, double clicks, and drag commands. This system was invented to assist people with disabilities to live an independent professional life.**

***Index Terms*—Computer mouse, head-operated, people with disabilities, tilt sensor.**

I. Introduction

OWING to the lack of appropriate input devices, people with disabilities often encounter several obstacles when using computers. Currently, keyboard and mouse are the most common input devices. Due to the increasing popularity of the Microsoft Windows interface, i.e., Windows 98 and Windows NT, computer mouse has become even more important. Therefore, it is extremely urgent to invent a simple mouse system for people with disabilities to operate their computers.

People with spinal cord injuries (SCIs) and who are paralyzed have increasingly applied electronic assistive devices to improve their ability to perform certain essential functions. Electronic equipment, which has been modified to benefit people with disabilities include communication and daily activity devices, and powered wheelchairs. A wide range of interfaces is available between the user and the device. These interfaces can be an enlarged keyboard or a complex system that allows the user to operate or control a movement with the aid of a mouthstick, an eye imaged input system, electroencephalogram (EEG) signals [1], [2], [7]–[19] and an infrared or ultrasound-controlled mouse system (origin instruments' headmouse and prentke romish's head master) [3]–[6], etc. However, for many people the mouthstick method is not accurate and comfortable to use. Likewise, the eye movement and the EEG methods are capable of providing only a few controlled movements, have slow response time for signal processing and require substantial motor coordination. Within the infrared or ultrasound-controlled computer mouse, there are two primary determinants that are of concern to the user. The first one being whether the transmitter is designed to aim at an effective range or not with respect to receiver, the other one being whether the cursor of computer mouse can move with his head or not. These considerations increase the load for people with disabilities. Thus, alternative systems that utilize commercially available electronics to perform tasks with easy operation and easy interface control are sorely required.

The ability to operate a computer mouse has become increasingly important to people with disabilities especially as the advancement of technology allows more and more functions to be controlled by computer. There are many reasons for people with disabilities to operate a computer. For instance, they need to acquire new knowledge and communicate with the outside world through the Internet. In addition, they need to work at home, enjoy leisure activities, and manage many other things, such as home shopping and internet banking. This research focuses on the design of a tilt sensor-controlled [20] computer mouse for patients who are quadriplegic from a cervical cord injury and have retained the ability to rotate the neck. The tilt sensors or inclinometers detect the angle between a sensing axis and a reference vector such as gravity or the earth's magnetic field. In the area of medicine science, tilt sensors have been used mainly in occupational medicine research. For example, application of tilt sensors in gait analysis is currently being investigated. Otun and Anderson employed a tilt sensor to continuously measure the sagittal movement of the lumbar spine [21]. Andrews *et al.* [22] used tilt sensors attached to a floor reaction type ankle foot orthosis as a biofeedback source via an electrocutaneous display to improve postural control during functional electrical stimulation (FES) standing. Bowker and Heath [23] recommended using a tilt sensor to synchronize peroneal nerve stimulation to the gait cycle of hemiplegics by monitoring angular velocity. Basically, tilt sensors have potential applications of improving the abilities for persons with other disabilities [20]. As stated, the study presents a head-operated computer mouse that uses two tilt sensors placed in the headset to determine user's head position and to function as a simple head-operated computer mouse. The tilt sensors can sense the operator's head motion up, down, left, and right, etc. Accordingly, the cursor direction can be determined.

II. Methods

The configuration of the computer mouse interface controlled with tilt sensors is shown in Fig. 1. The system replaces the original computer mouse with two tilt sensors which are mounted onto a headset worn by people with disabilities. The tilt sensors are attached to both the front and lateral side of the headset, respectively.

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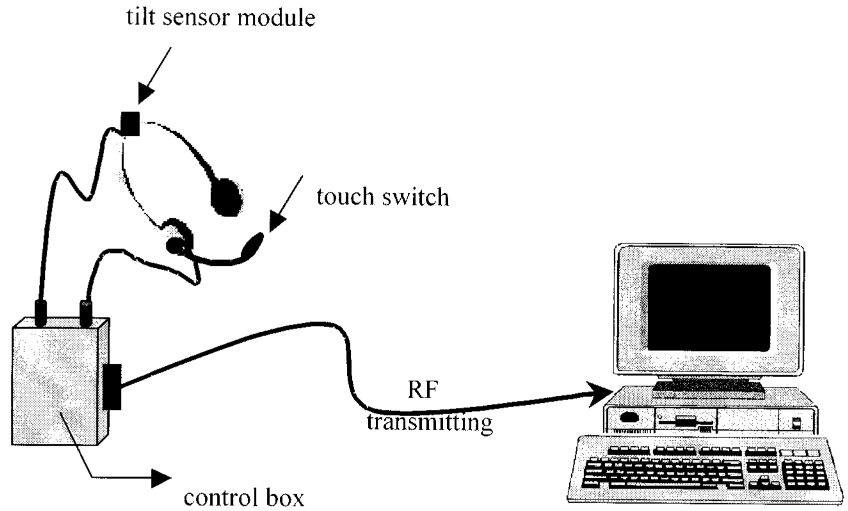

Fig. 1. Configuration of computer mouse interface controlled by tilt sensors to be used for people with disabilities.

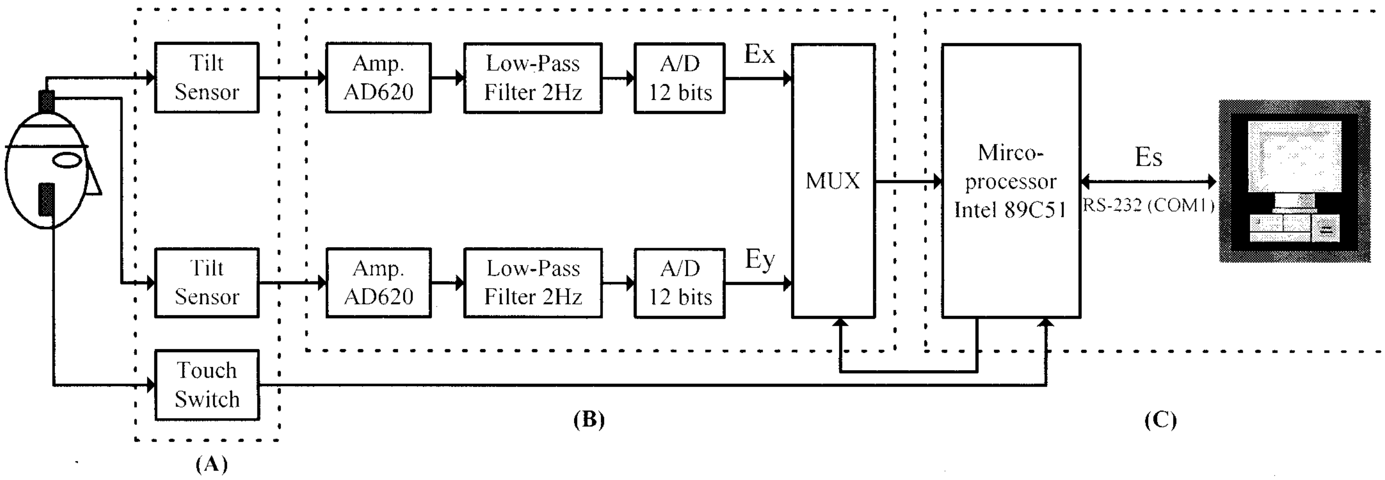

Fig. 2. The block diagram representation of the tilt sensors-controlled computer mouse interface.

The user performs to control computer mouse in order to move the cursor and perform all necessary functions in Windows 98. There is a touch switch attached to the headset and close to the user's cheek. People with disabilities can puff their cheek to trigger the touch switch and perform mouse functions for single click and double clicks. This mouse controlled functions include: up, down, left, right, upper-left, upper-right, lower-left, lower-right, drag, single click, and double clicks. The block diagram representation of the tilt sensors-controlled computer mouse is shown in Fig. 2. The circuit of computer mouse interface controlled by tilt sensors is composed of three major elements: 1) the tilt sensor module; 2) the signal-processing module; and 3) a main controller e.g., the Intel-8951 microprocessor.

A. The Tilt Sensor Module

The tilt sensor module, as shown in Fig. 2(A), links the computer mouse interface to people with disabilities. The tilt sensor module includes two tilt sensors with each weighing roughly 20 grams. The tilt sensor normally uses inertia to detect the tilt from the gravity vector and it contains an inertial element that senses gravity and a signal-transforming element. As the body of the sensor tilts, gravity causes the inertial element to move proportionately, which is then converted into quantities such as resistance, capacitance, and current changes by using various signal-transforming techniques. In this research, we have tested a tilt sensor called magnetoresistive tilt sensor (Model UV-1W) commercially available from Midori American Corp. Its change in resistance is proportional to the tilt angle of the sensor's body with respect to certain angular range [20].

The detectable range of the tilt sensors in this study is any angle within $\pm 45°$. The neutral output voltage of the sensor after calibration is $+2.5$ V with no variation detectable in regard to angle. The standard output voltage (varying between 0–5 V) is proportional to the detected range (varying between $-45°$ and $+45°$). The output voltage is defined as 2.5 ± 1 V with the effect of noise boundary being included as well to avoid either oversensitivity from sensor or any unintended head motion as a result of which they can cause the mouse/cursor to shiver and overreact. It can be seen that the output voltage must be greater than 3.5 V or less than 1.5 V in order to have mouse travel any left/right or up/down displacement. The direction of mouse movement (Es) is represented by as

$$Es = Ey/Ex \tag{1}$$

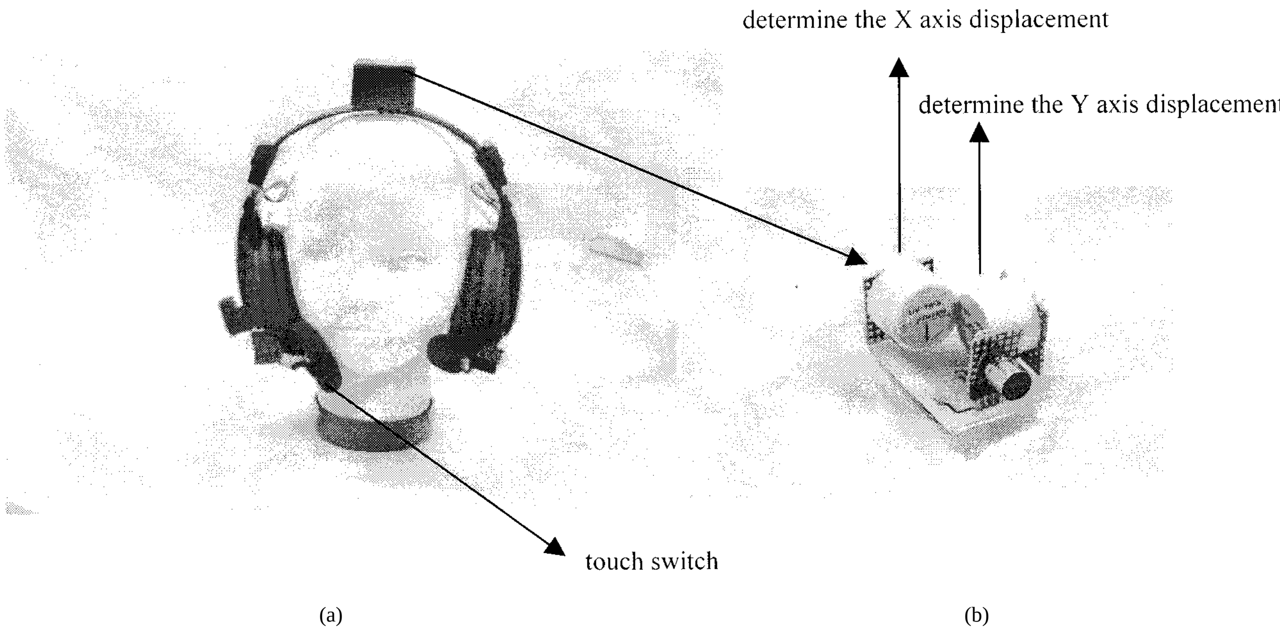

Fig. 3. The headset unit of the new computer mouse (a) The headset unit with a tilt sensor module and a touch switch. (b) The tilt sensor module within two tilt sensors.

where Ey is the vertical displacement of the tilt sensor and Ex is the horizontal displacement of the tilt sensor.

If (($Ey = 2.5 \pm 1$ V) Λ ($Ex \neq 2.5 \pm 1$ V)), then mouse cursor moves left/right (vertical).
If (($Ey \neq 2.5 \pm 1$ V) Λ ($Ex = 2.5 \pm 1$ V)), then mouse cursor moves up/down (horizontal);
If (($Ey > +3.5$ V)) Λ ($Ex > +3.5$)) then mouse cursor moves upper-right with a slope Es.
If (($Ey > +3.5$ V)) Λ ($Ex < +1.5$)) then mouse cursor moves upper-left with a slope Es.
If (($Ey < +1.5$ V)) Λ ($Ex < +1.5$)) then mouse cursor moves lower-left with a slope Es.
If (($Ey < +1.5$ V)) Λ ($Ex > +3.5$)) then mouse cursor moves lower-right with a slope Es.

Therefore, the cursor controlled by the tilt sensor cannot only move in vertical or horizontal direction, but it can also move in a diagonal.

One 9-V battery supplied the power required for all devices contained within the control box, including the following: tilt sensors, touch switch circuitry, signal-processing circuitry, and microprocessor circuitry of the circuitry control box. This control box measured $8 * 3 * 12.5$ cm^3 in dimension and weighs roughly 150 g, which allows the operator to conveniently attach it to the waist or another part of the body.

B. The Signal-Processing Module

The signal-processing module, as shown in Fig. 2(B), consists primarily of three components: an amplifier, a low-pass filter, and analo-to-digital (AD) converters. In order to receive a small signal from tilt sensors, a highperformance amplifier (AD620) was employed in this system. The gain of the amplifier was set at 500. A second order low-pass radiatively coupled filter of 2 Hz is designed for the system, which can reduce the acceleration effects and remove the noise frequency. The 12-bit AD converters are used to digitize the signals of the tilt sensors.

C. The Main Controller, Intel-8951, Microprocessor

The Intel-8951 microprocessor is the main controller of the system, as shown in Fig. 2(C). Port1 and Port2 of the Intel-8951 microprocessor can receive the digitized signals from the tilt sensors via the signal-processing module. At the same time, Port2 receives the trigger signal from the touch switch to perform the click motions. A parallel-to-serial method is deployed via Port3 to dispatch signals capable of controlling input motion of the computer mouse (COM1). Port2 dispatches all control signals to the operator to confirm that his input motion has been completed. The signals that are required by the surrounding circuits include LED indicators and speech chip (ISD2500) control to be used as a visual and audio feedback, respectively.

Lateral and up-and-down motions from user's head can be detected by the tilt sensors and are fed into the microprocessor via a multiplexer for analysis and processing. The microprocessor maps the fed-in signal immediately to its command code as Port 1 receives signal from one AD converter only. It commands the mouse to have the cursor move in vertical or horizontal direction, i.e., up, down, left, and right. When Port 1 receives signals from two AD converters, it enables the mouse to move in a diagonal, i.e., upper left, lower left, upper right, or lower right. The slope of the line is determined by comparing the two input signals from the converters. The Port 3 of the microprocessor converts the parallel data into serial data and transmits these data to the computer through a radio-frequency (RF) method. The serial port (COM 1) of the computer forward both the command codes and digitized trigger signals (single click, double clicks, and drag) to the computer. An application program written by visual basic (VB) language reads the command codes sent by serial port (COM 1) regarding the mouse activities from the microprocessor via API. These codes are converted in order to carry out the motions of up, down, left, right, upper left, lower left, upper right, lower right, single click, double clicks, and drag. Also, a speed control function for cursor/click is built

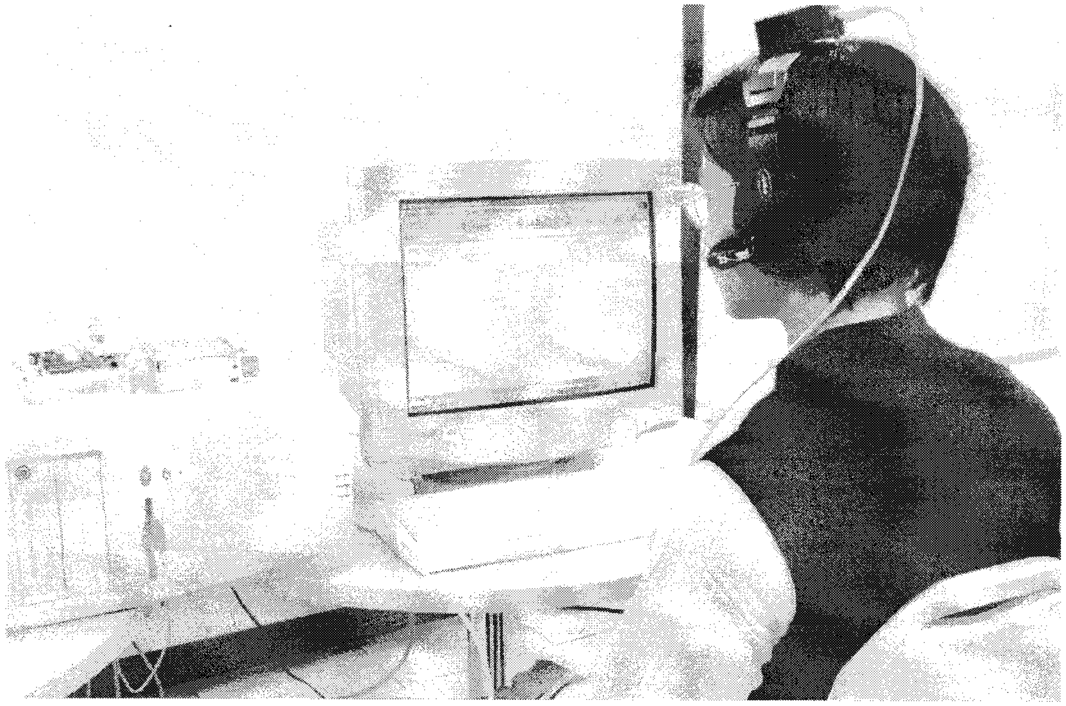

Fig. 4. The arrangement of the head-operated computer mouse operated by a people with disabilities.

in the application program. A set of desirable controlling parameters may be preset to satisfy the user depending on how familiar the operator is with the system. The application program is positioned in the top level of the Windows operation system such that the head-driven mouse may work with the rest of Windows-based applications.

For system evaluation, 12 people (all men, 33–43 years old, six are nondisabled and six are individuals with quadriplegia) who had experience in operating computer were selected for this study. The six nondisabled individuals had their whole bodies were constrained in a fixed and stationary position, except neck and head movements are free as that in the spinal cord injured group, and were assigned as the control group. The rest of six SCI people with quadriplegia were assigned as the experimental group. All of them were given 30 min training prior to using this newly developed computer mouse. In addition, they all received instructions using 30 commands in controlling the computer mouse [up, down, left, right, upper-left, upper-right, lower-left, lower-right, drag, single click, and double clicks (see the Appendix)]. Then, they were asked to input as accurate as possible and not to correct their errors. During the test, the clinician read each command to prompt the users' input motions. To begin with, the clinician read the first command to prompt the users' first input motion. Then, the clinician read each of the following commands to prompt the user to input them as soon as the user had completed the input from the previous command. Therefore, the speed of using this interface is up to the user himself. The clinician recorded the number of correct input motions and the time needed to finish 30 input motions. Then, both the percentage of accuracy (number of correct input motions divided by 30 and multiplied by 100%) and the time needed for every user were calculated for the control group and the experimental group, respectively. Statistical analyses (average values, standard deviations and independent t-test) were performed by using the statistical software [statistical package for the social sciences (SPSS)].

III. Results

In order to accomplish the objective of operating the computer and communicating a message through the WorldWide Web (WWW), all the individual needs to do is put on our newly developed headset, as shown in Figs. 3 and 4.

The test results were listed for users in both control and experimental groups, as shown in Table I and in Fig. 5. The average accuracy of this experiment for both the control group and the experimental group are 97.8$\pm$2.6% and 95.1$\pm$4.9%, respectively. The average time needed for the control group and the experimental group are 3.5$\pm$1.1 min and 4.9$\pm$2.0 min, respectively. An independent t test revealed that the differences in the average accuracy and the average time of the control group and the experimental group are not significant ($p > 0.05$). This means that the newly designed computer mouse interface is user friendly with respect to nondisabled people or the people with disabilities (SCI with quadriplegia).

IV. Summary

The increasing number of various accidental injuries over the years has resulted in a dramatic increase in the population of individuals with disabilities. Although there are numerous devices that can supplement the loss of function for people with spinal cord injuries, there is still a substantial difference in terms of their convenience and accuracy. Most devices are designed to serve as a computer mouse supplement for the individuals with disabilities by utilizing methods of mouthstick, eyeball movements, or eyeball-imaging to complete the input motion [7], [12], [14], [15],

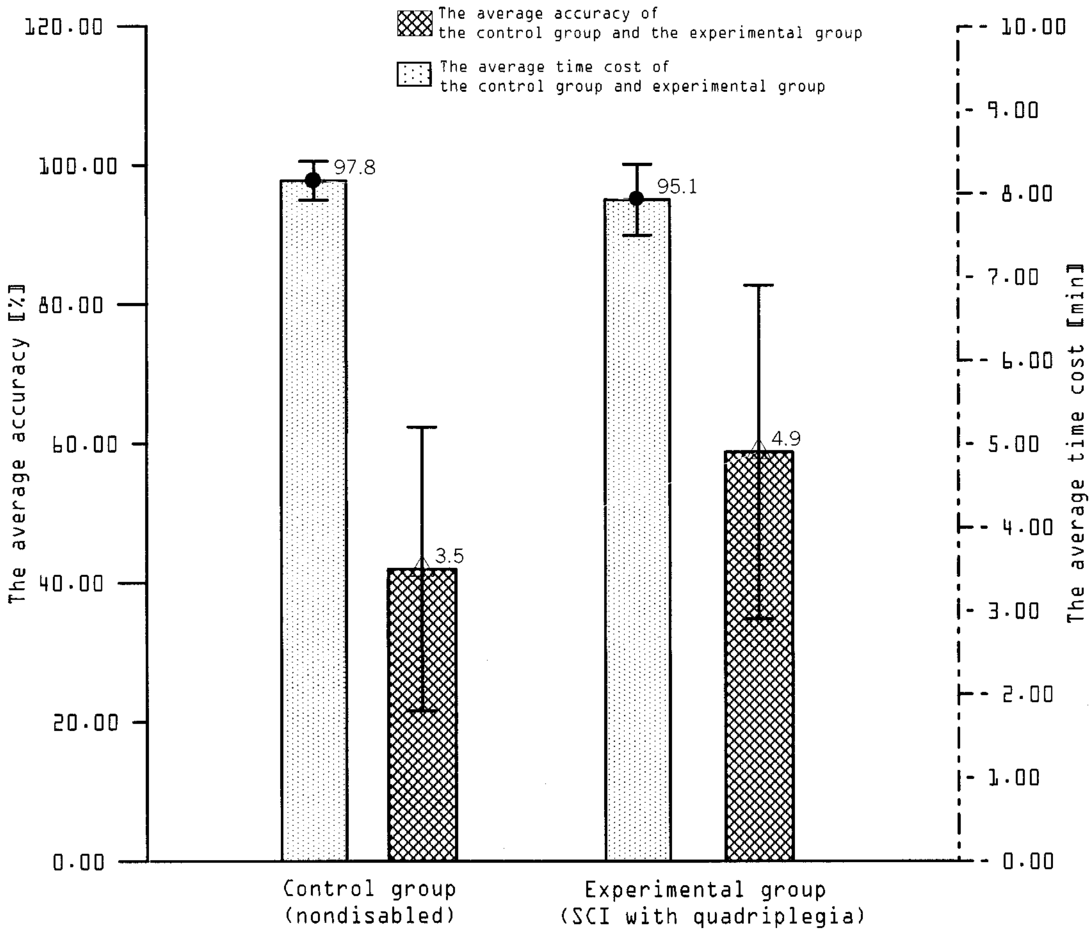

Fig. 5. The test results derived from the tilt sensors-controlled computer mouse interface.

TABLE I
THE TEST RESULTS OF THE NEW COMPUTER MOUSE INTERFACE

	Control group (6 nondisabled subjects)	Experimental group (6 SCI subjects with quadriplegia)	p
average accuracy (%)	97.8 ± 2.6	95.1 ± 4.9	p>0.05
average time cost (min)	3.5 ± 1.1	4.9 ± 2.0	p>0.05

[18], [19]. Although mouthstick provides reasonable function and allow successful input through the computer mouse, it frequently lack good sanitation or convenience because it is orally activated. Similarly, eyeball movement and eyeball-imaging based systems rely on high-level imaging analysis (with questionable accuracy), and they require a much longer operating time to input a number or a letter. As the head-controlled mouse relies on infrared and ultrasonic signals, the transmitter placed on the head sends signals to the remote receiver after a motion is detected. However, the user must focus on the cursor's movement on the computer screen and assure that the transmitted signals are within the reception range of the receiver. As a result, these devices certainly cause troubles for people with disabilities. In addition, these systems have disadvantages such as expensive instrument costs and the requirements of extended operational training.

In the era of new millennium, it is our concern that individuals with disabilities do not become technological orphans in the areas of electronics and computers. Specifically, for people with disabilities to overcome inconveniences in their daily lives, we have utilized the least amount of circuitry as well as highly accurate control system to generate devices. The system presented in this paper allows people with disabilities to avoid the need to use uncomfortable input methods such as clutching a mouthstick. Rather, this system employs a tilt sensor module to control the computer mouse in response to the movements of neck's rotation. There are several user-friendly features also included in this system. For example, it allows the user to verify if his operation is correct, and it provides an LED indication and speech chip as visual and audio feedback to the user each time the input motion is completed. As a result, this system outperforms the mouthstick-based system in terms of providing users the advantages such as convenience, accuracy, and sanitation. In addition, a headset-type control method is especially helpful for those who are quadriplegic due to spinal cord injuries. The quantitative data also revealed that following limited training, nondisabled and people with disabilities can operate the system with an accuracy that exceeds 95%. On average, it took 7–9 s to complete a single mouse motion. The result shows people with disabilities can operate the system as good as nondisabled. Furthermore, when compared to the previously developed infrared-controlled human–computer mouse interface [3], the newly developed system can complete a single mouse command 3–4 s faster, which proves the practical value of the system. People with disabilities can also mount the tilt sensor module on a prosthesis, a protective gear, or on a powered wheelchair to achieve the objective of using the computer mouse easily and sanitarily.

This computer mouse interface, which is controlled by tilt sensors, utilizes current circuit technology to accomplish the control of a computer mouse system effectively. In the future, this interface can be introduced into many control systems at home such as powered wheelchairs, telephones, and appliances with great potential demanded by the market.

Appendix

The 30 commands are listed as following:
Up, down, left, right, upper-left, upper-right, lower-left, lower-right, drag, single click, double clicks, left, right, upper-left, upper-right, lower-left, lower-right, drag, up, low, left, right.

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