Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

M3S-based Electrical Wheelchair with Head-controlled Device

Show-Hong Chen[1, 5], Yu-Luen Chen[2], Te-Son Kuo[1], Chiung-Yu Chu[3], Chao-Nan Hung[4]
[1]Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan, R.O.C.
[2]Department of Electronic Engineering, Hwa-Hsia College of Technology and Commerce, Taipei, Taiwan, R.O.C.
[3]Department of Electrical and Control Engineering, National Chiao Tung University, Hsinchu, Taiwan, R.O.C.
[4]Department of Computer Science and Information Engineering, Tung Nan Institute of Technology, Taipei, Taiwan, R.O.C.
[5]Realtek Semiconductor Corporation, Hsinchu, Taiwan, R.O.C.

Abstract— **The motivation of this research is to improve the ability of ambulation for people with a certain degree of disability. The control of the wheelchair is using two tilt sensors as an input-controlling module. One of the tilt sensors detects the anterior/posterior tilting of the head and moves the wheelchair forward/backward, the other distinguishes the left/right swing of the head. In order to increase the safety of this system, the M3S protocol established by the European Commission is also applied to this research. The system based on M3S protocol has the advantage of real-time signal transmission and emergent status monitoring for SCI patients with C2-C4 level.**

Keywords— **M3S, SCI patients, Tilt Sensor, Wheelchair**

I. Introduction

In the past the assistant device was designed with a unique connection, whereas a single input device was connected to a single output device which had neglected integral significance. These devices were not completely compatible with each other and had a rather poor integrated safety system. Furthermore, owing to severe degree disabilities who were quadriplegic from a cervical cord injury and had retained the ability to rotate their neck, were unable to switch arbitrarily between each connecting device by themselves, these one-to -one connected mechanism were not suitable for them. Therefore, it was extremely urgent to invent a connected interface and a simple input device for people with disabilities to operate in their wheelchair.

In order to integrate different kinds of device and improve the facility of operation, Multiple Master Multiple Slave (M3S) is intelligent interface developed from European Community (EC) programs and individual people in the 90s. M3S protocol provides the standard interface between the input device and output device. A M3S system is based on the bus and devices. The bus of M3S contains three parts: 2 lines for digital communication (Controller Area Network bus, CAN bus), 2 lines for power distribution (Power bus) and 2 lines for safety features (Safety bus). [1],[2]

Due to SCI patients at the higher levels can only depend on their head movements, the traditional joystick-controlled method is not suitable for these users. In recent research, tilt sensors have been widely applied in the medical engineering field. Such as, Chen [5] employs two tilt sensors placed in the headset to determine head position and to perform a simple head-operated computer mouse. Bowker and Heath [6] recommended using a tilt sensor to synchronize personal nerve stimulation to the gait cycle of hemiplegics by monitoring angular velocity. As mentioned above, this research focuses on the design of a tilt sensor-controlled wheelchair where severely disabled SCI patients would only utilize the position of the head-swing to decide whether the wheelchair should move forward/backward or make a turn.

This research is to combine the head-controlled device which includes two tilt sensors and two touch switches, motor-controlled device and CCM (Control and Configuration Module) device with wheelchair, which is based on M3S protocol. This structure is able to provide the wheelchair user with optimal control over his mobility and personal communications through one input device best suited to the user's needs, to allow easy modification or expansion of a wheelchair's facilities as their needs change and to ensure that the wheelchair user is safe.

II. Methodology

This system consists of head-controlled input device, output and Control and Configuration Module (CCM) device, which are all M3S-based. All devices are connected with the M3S bus. The structure is illustrated in Fig. 1. All of these devices have safety monitoring construction including Dead Man Switch (DMS) and Key Switch circuits. The detailed information about this system is as follows:

A. Input device

This system uses a head-controlled device instead of a joystick so that the corresponding analog voltage can be gathered by the tilt sensor in different levels. After converting the 10 bits of digital voltage, the analog voltage is transmitted to the analog digital converter (ADC) circuit. Finally, the digital signal is conveyed by CAN module and CAN transceiver.

1) The Tilt Sensor Module: The tilt sensor module includes two tilt sensors, each weighing roughly 20 grams. The tilt sensor normally uses inertia to detect the tilt from the gravity vector and contains an inertial element that senses gravity and a signal-transforming element. As the

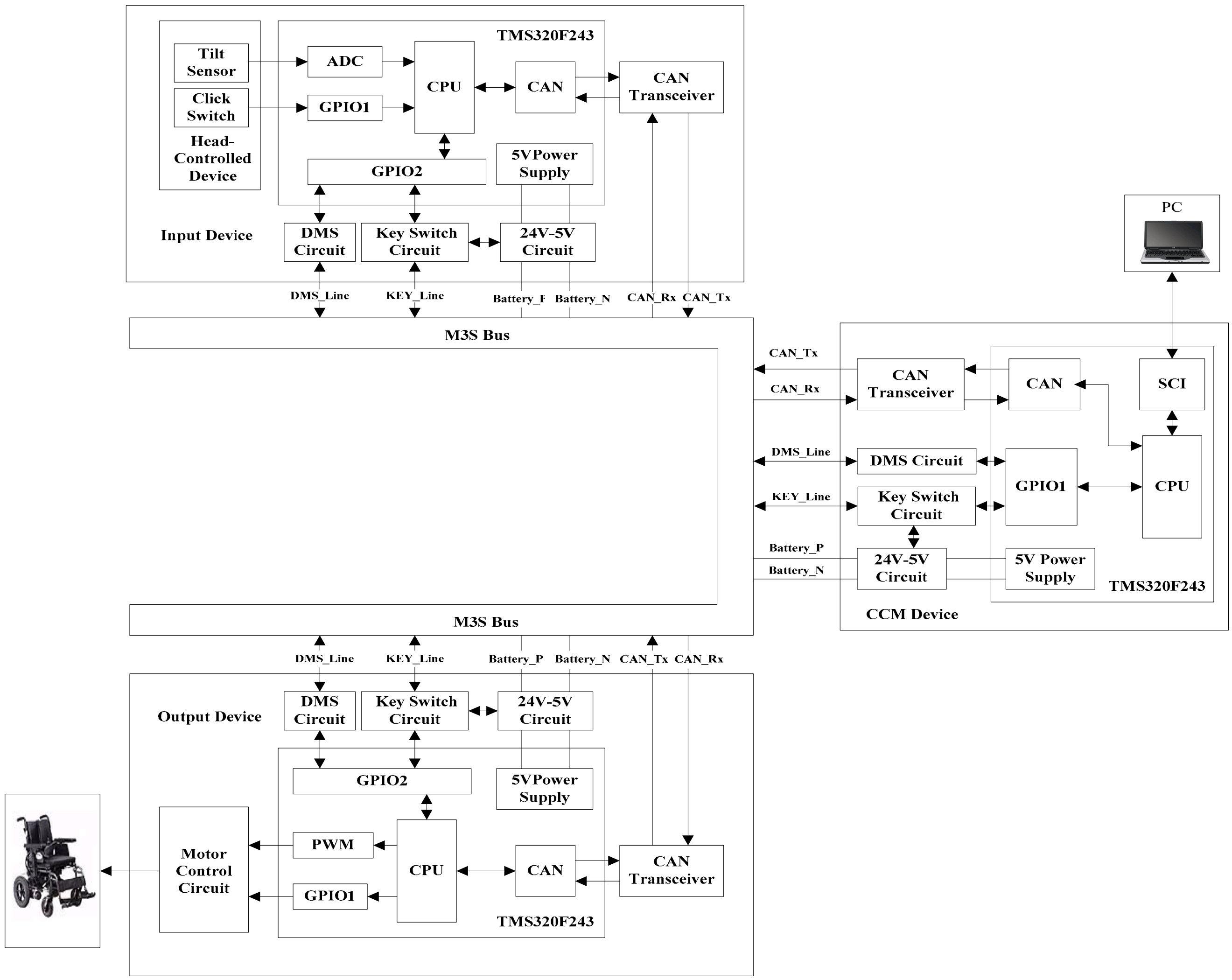

Fig. 1. The system construction

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. Its change in resistance is proportional to the tilt angle of the sensor's body with respect to a certain angular range [5]. For example: if the user gives 5V DC power supply on the tilt sensor module, and the angle of the tilt is equal to 90°, then the corresponding maximum output voltage will be 3.26V; if the angle of the tilt is equal to -90°, then the consistent minimum output voltage will be 1.74V. The neutral output voltage of the tilt sensor after calibration is 2.5 V without variation of the angle. Because this system is designed for SCI patients, the maximum ranges of the swing angles must be restricted to between -45° and +45°, and the corresponding voltage varies between 2.07V and 2.93V, as shown in Table 1.

TABLE 1
THE RELATIONSHIP BETWEEN TILT SENSOR DEVICE AND WHEELCHAIR DIRECTION

Wheelchair Direction	Tilt Sensor Output Voltage
Left-Forward	$2.55V \leqq V_y < 2.93V$ and $2.07V \leqq V_X < 2.45V$
Forward	$2.55V \leqq V_y < 2.93V$ and $2.45V \leqq V_X < 2.55V$
Right-forward	$2.55V \leqq V_y < 2.93V$ and $2.55V \leqq V_X < 2.93V$
Turn Left	$2.45V \leqq V_y < 2.55V$ and $2.07V \leqq V_X < 2.45V$
Stop (Neutral Position)	$2.45V \leqq V_y < 2.55V$ and $2.45V \leqq V_X < 2.55V$
Turn Right	$2.45V \leqq V_y < 2.55V$ and $2.55V \leqq V_X < 2.93V$
Left-Back	$2.07V \leqq V_y < 2.45V$ and $2.07V \leqq V_X < 2.45V$
Back	$2.07V \leqq V_y < 2.45V$ and $2.45V \leqq V_X < 2.55V$
Right-back	$2.07V \leqq V_y < 2.45V$ and $2.55V \leqq V_X < 2.93V$

2) ADC module: The 10 bits of ADC circuit are to convert the analog voltage of the tilt sensor into the binary digital voltage. The control region is separated into three

sections by 556H and 450H (hexadecimal) on each axis, shown in Fig. 2.

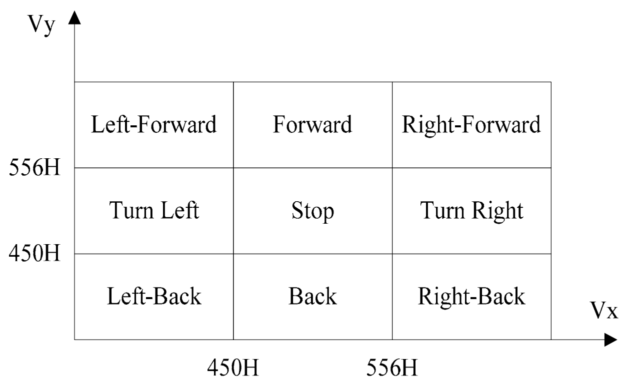

Fig. 2. The control region

3) Controller Area Network (CAN) Module: The kernel of CAN module uses a serial communication protocol and supports the distributed control in real time. The CAN data frame mainly consists of seven fields: start of the frame, arbitration field, control field, data field, cyclic redundancy check (CRC) field, acknowledgment and end of frame bits. [3],[4] Each device in the M3S system has a specific identification, so it must be declared the priority and serial number arbitration protocol (SNAP), called the device number, must be in arbitration fields before the development.

4) The main controller, TMS320F243, Digital Signal Processor (DSP): The TMS320F243 is the major core of this system. The right/left and anterior/posterior motions from the user's head can be detected by the tilt sensors and are fed into the ADC module for analysis and processing. The control region is partitioned into nine subdivisions by the digital level (556H and 450H), including forward-left, forward, forward-right, left, stop, right, back-left, back and back-right directions. The controller maps the fed-in signal immediately to its command code as it receives signal from the ADC module. The command code will be transmitted via the CAN_Tx line. General purpose Input and Output (GPIO1) module receives the control signals from the touch switches and dispatches them to the controller to execute the touch switch functions. The left touch switch is used for braking, and the right touch switch is to send the signal, turn on the system, to the Key switch circuit. Furthermore, the controller receives the status signal from the DMS circuit and immediately deals with the emergency.

B. Output device

When the CAN module and CAN transceiver correctly receive the frame message via the CAN_Rx line, the controller will dissolve the CAN frame into the arbitration field and the control field. This serial control data is converted to parallel control signals and is dispatched to motor control circuit via the GPIO1 module. At the same time, the PWM module provides a serial of digital pulses, on-time duration is 50% and off-time duration is 50%, to handle the rotational speed and the torque of the motor. Furthermore, while gaining the control signal from the left touch switch, the output device's controller will execute the brake function by stopping the PWM signal transmitting to motor control circuit. The wheelchair halts.

C. CCM device

The CCM application software, designed by Visual Basic (VB) language, is to set the SNAP of the device with 8 bits of data lengths, to allocate the connection between head-controlled device and motor control circuit and to check the emergent status which is sent from the DMS circuit and Key switch circuit on every device with polling mode.

D. Safety monitoring construction

Besides the error detection of control signal on CAN module, DMS circuit and Key Switch circuit provide another safety mechanism to monitor and to make sure the device is in accurate operation. When the right touch switch is active on the head-controlled device, GPIO2 in input device sends the KSL_ON signal to the KEY_Line. The controller will set the Key switch latch and the current will be provided from the Battery_P line. All devices then start working. However, the KSL_CUTOUT signal is transmitted; the KEY_Line is connected to the Battery_N line and the power supply on each device is removed. As soon as the head-controlled direction locates at the neutral position, DMS function turns low. The power supply is removed from the devices.

III. RESULTS

Six SCI patients with C2-C4 level, who were quadriplegic from a cervical cord injury and have retained the ability to rotate their neck, participated in the clinical experiments as an experimental group. The six SCI patients with C5-C6 level, who had used a joystick wheelchair by chin for over a year were assigned as the control group. The wheelchair was implemented by using M3S-based and head-controlled devices, as shown in Fig. 3. All of them were given 30 minutes training prior to clinical experiments, so as to accommodate the operation of the wheelchair's movement. During the experiments, the subjects were asked to perform three tasks, shown in Fig. 4. They drove the wheelchair along the dash-line in these tasks. The time required for the subjects to operate M3S-based wheelchair with head-controlled device were recorded. Statistical analyses (average values, standard deviations and independent t-test) were performed by using the statistical software [statistical package for the social sciences (SPSS)]. The test results were revealed for users in both the control and experimental groups, as shown in Table 2.

An independent test showed that the differences in the average time of the control group and the experimental group are not significant ($p>0.05$). This means that this newly designed electrical wheelchair with head-controlled device, which is based on M3S protocol, is user friendly with respect to disabled people with C2-C4 level or with C5-C6 level.

IV. Conclusion

The results reveal that the head-controlled device should still be a better alternative for SCI patients with C2-C4 level, unsuited to traditional input device. The average time in every task for the control group and the experimental group is according to the operation with good flexibility and proficiency. Furthermore, because of the different sensitivities of neck swing, the different control range should be adjusted for individuals before operating. While they have given more training prior to operate, this system will be user friendly.

In this research, the head-controlled device, the motor control circuit and basic CCM function have been combined with electrical wheelchair through the M3S bus. This structure can provide the wheelchair user over his mobility and personal communications through head-controlled device best suited to the user's needs. It also allows easy modification or expansion of a wheelchair's facilities as their needs change, as long as these devices are based on M3S protocol.

Acknowledgment

This work was supported by the National Science Council, Taiwan, R.O.C. under grant NSC93-2213-E-146-001.

Fig. 3. M3S-based electrical wheelchair with head-controlled device

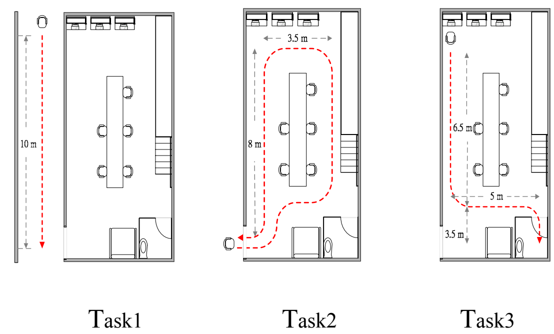

Fig. 4. Clinical experiments

TABLE 2
THE TEST RESULTS

Clinic test	Control group (6 SCI patients with C5-C6 level)	Experimental group (6 SCI patients with C2-C4 level)	p
Task1 (sec)	13.57 ± 1.19	15.64 ± 2.31	P>0.05
Task2 (sec)	38.81 ± 3.94	43.17 ± 4.95	P>0.05
Task3 (sec)	18.89 ± 1.97	20.51 ± 1.99	P>0.05

References

[1] M3S specification, version 2.0 from the Dissemination office, TNO Institute of Applied Physics, P.O. BOX 155,NL 2600 AD Delft, The Netherlands.

[2] Sven Linnman, "M3S: The Local Network for Electric Wheelchairs and Rehabilitation Equipment" *IEEE trans. On Rehabilitation engineering*, vol.4,No.3, September 1996.

[3] TMS320F243/F241/C242 DSP Controllers Reference Guide System and Peripherals Literature Number: SPRU276C January 2000.

[4] *CAN Specification, Version 2.0*, ROBERT BOSCH GmbH, 1991.

[5] Yu-Luen Chen, "Application of Tilt Sensors in Human–Computer Mouse Interface for People With Disabilities "*IEEE Trans. on Neural Systems and Rehabilitation Engineering*, Vol. 9, No. 3, September 2001.

[6] P. Bowker and G. H. Heath, "Control of peroneal functional electrical stimulation using a magneto transducer to monitor angular velocity of the knee," in *Proc. World Cong. Int. Soc. Prosthesis Orthopaedics*, Melbourne, Australia, June 1995, p. 61.