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Development of a cart for independent mobility assistance for non-ambulatory children

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Abstract— **Some parents of non-ambulatory children are not eager to allow their children to use powered wheelchairs because of apprehension of further deterioration of their functionality and the risk for accidents. The authors think that not all but some such children could develop their ability to operate powered wheelchairs and might expand their knowledge about the circumstances and interests in them. Thus we made a prototype cart for them eventually to experience motion by themselves. Based on a 6-wheeled chassis, the two middle wheels are driven with a traction roller drive system. We had been testing this prototype with a child with cerebral palsy for one year. Acquisition of skills in pushing switches and enjoyment of motion were confirmed. However, we encountered several problems such as difficulty in rolling on a carpet and in handling due to its weight. The ability to record moving speed and operation of input devices helps rehabilitation experts to conduct quantitative performance evaluation. To solve these problems, we manufactured another prototype. The second prototype was tested with another child with cerebral palsy for one year. The problems were solved. She acquired the operation skills necessary to operate the prototype with four switch operation.**

I. Introduction

In Japan, most of local governments do not permit provision of powered wheelchairs to children under 10 following an announcement of the Ministry of Health, Labour and Welfare[1]. People think that those children do not have good judgment and their physical functions might deteriorate and that parents hesitate to provide such children with powered wheelchairs, because they cannot accept their children's disabilities[2][3].

However, the use of a powered wheelchair by a 3-year-old child is reported [2] and a spinal-muscular-atrophy family group produced an educational video, "Powered wheelchairs for independence", showing a 3-year-old boy who is operating a powered wheelchair skillfully and enjoying it. Spontaneous mobility leads to independence and could, we hope, promote mental and social growth[4][5].

The authors think that it is important for children who have difficulties even in using powered wheelchairs to experience motion and possibly move by themselves. For that reason, we manufactured a prototype (the first model) of a cart for independent mobility assistance which allows users to get on while sitting in a chair with seating and positioning system[6]. We tested it at several nursing institutes and evaluated it in order to make improvements. After a one-year test, we manufactured the second model. At the beginning, we consider infants as suitable users, but now we include children under 10, because it is useful for them as a startup device for wheelchair. A feature of this cart is that users can get on it in various positions: sitting, sitting with legs stretched, supine and prone. They can get on it in their own chair with seating and positioning system.

Similar mobility assistance carts or wheelchairs have been developed [7]-[10] in various research institutes, but they are designed mostly to assist users to experience motion and operation of devices as amusement equipment. They do not have functions to record the operation of input devices or the trajectory of the movement in order to assist rehabilitation staff for rehabilitation evaluation.

In this paper, we describe the second prototype and the evaluation of usefulness through tests by a boy and a girl with combined cerebral palsy.

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II. Prototype of Cart for Mobility Assistance

A. Hardware

1)Mechanism

Figure 1 shows an overview of the second prototype and a picture with a CP user. The driving mechanism is inside a FRP cover. Table 1 lists the specifications of the second prototype.

2)Structure

The area for the ride is as wide as 620 by 1000 mm. This is large enough for a chair with seating and positioning system for children to get on. It is a block board covered with a carpet and fixed on a frame made of aluminum pipe which is 2mm in thickness and 22mm in diameter. It allows users to take the prone position, supine position or sitting position with legs stretched. The height is about 50mm, which is low enough for a caregiver to place a chair with the user in it. The prototype has 6 wheels in total. Four casters are placed at each corner of the prototype and two driving wheels are placed at 100mm behind the middle of the prototype, assuming the center of gravity comes near that point when riding in the seat. This

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allows the user to make small-radius turns and to turn easily.

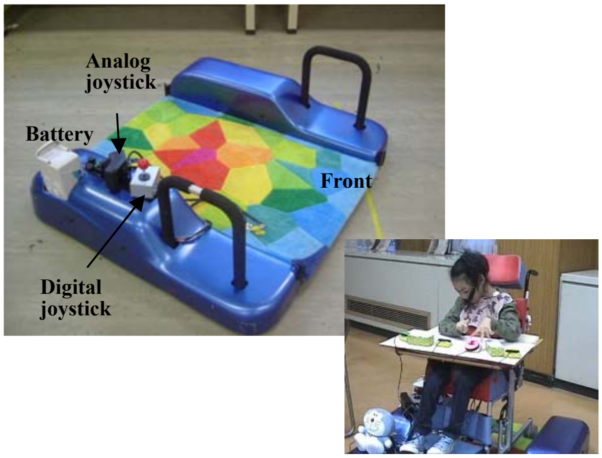

Fig.1 Overview of prototype, with a CP user

Table 1
Specifications of prototype

Item	*Type / value*
Number of wheels	6 wheels (4 casters)
Drive motor	AXH5100K-15(Oriental motor)
	DC24V brushless motor 100W Gear reduction ratio 15:1 Speed Max. 3200RPM
Drive wheel (middle)	φ8in. Width: $1\frac{3}{8}$ in.
Controller	Microcomputer H8 3052F
Battery	24V 8AHour (Lithium ion)
Base space	1000×620mm
Dimensions	1000×1090×110(rear210)mm
Mass	26kg

The casters are fixed to ends of aluminum pipe, which works as a sort of suspension. The cart is able without difficulty to go on level ground.

3)Driving mechanism

As driving mechanism, two gear-headed brushless DC servo motors, AXH5100K-15(Oriental Motor), are used. Each motor directly drives an 8 inch urethane solid tire fixed either on the left or the right side of the prototype. The rated output of the motor is 100W, which is large enough to go up a one-to- twelve ratio slope supposing the total mass is 100kg. The motor provides with pulse output (30 pulses per output axle rotation) that is useful for computing speed.

4)Control circuits

An H8/3052F (Renesas Technology) microcomputer board is used. It receives inputs from switches or analog inputs from a joystick as speed and direction commands and outputs analog signal to DC motor controllers as speed reference signals. As switch inputs for controlling motion, four digital inputs are used. They are corresponding to forward, backward, turn right and turn left commands. Combining two inputs of the above, forward left, forward right, backward left or backward right command are achieved. For children familiar with PS2 (Play Station 2, Sony) controller, a wireless PS2 controller is provided. As a safety measure, a wireless switch interface is connected to the controller board for emergency stop and release by the attendant. A bumper switch is also provided to detect collisions. For controlling orientation of the prototype, a vibration gyro sensor CRS03-02B (Silicon Sensing Systems Japan) is used. For recording the left wheel rotation, the right wheel rotation, angular velocity, switch inputs and joystick inputs, a SmartMedia memory card (Toshiba) is used. The data are analyzed to evaluate cart operation by the subject. A piezo-electric sounder and a LED ball are used for various warning to the rider or the attendant. Finally, an mp3 player is provided to confirm inputs by the rider and to warn children standing or playing beside the prototype by playing music.

6)Input devices

Switches for controlling motion can be connected to the system through audio mini-jacks. For evaluation tests push button switches with two different operation forces (350gf, 100gf on peripheral), body button switches (Tash), were used. Users choose one input, two inputs or four inputs according to their operation ability. Digital inputs can be input using a digital joystick which allows commands for 8 directions. For children with more skills in operation, an analog joystick will be introduced. This might prepare users for operation of a powered wheelchair. The wireless PS2 controller (Logicool) is useful for both user and attendant. For some users, cables are a nuisance and prevent users from concentrating on operation. The controller can be placed anywhere, but acquiring skill in its use is also necessary.

7)Output devices

For some children, input confirmation is helpful. Light and sound reaction can be added. As light output, a LED ball is provided which has 32 LEDs around the sphere. For sound output, we provide either a beep sound for simplicity or mp3 format sound to attract the user by playing a sound familiar to the user. The confirmation output will not be needed when the user comes to understand the relation between inputs and motion. Mp3 sound is played by an mp3 player which is controlled through a serial communication line.

B. Software

Programs developed here are a control program for the prototype and a display and analysis program for recorded data on a memory card, which is used for evaluation of user operation.

1)Control program for the prototype

Four operating modes are provided for switch operations. Two of them are semi-automatic and are used to allow children to experience various motions interactively. The other two are manual and used to acquire voluntary motions.

The semi-automatic modes are

a. One-switch mode: This mode plays a sequence of motions which are predefined such as going back and forth, turning clockwise and turning counter-clockwise, each time a user clicks the switch. All motions return the cart almost to the original position on the assumption that the playing area is limited.

b. Four switch mode: Each switch corresponds to predefined motions. The motions are similar to one-switch mode.

The manual modes are

a. No-time-limit mode: Four switches correspond to forward, backward, spinning clockwise and spinning counter-clockwise. Selected motions continue until the user releases the switch.

b. Time-limit mode: For some children it is hard to release switches. To avoid unnecessary motions, this mode has maximum duration for each input. The default is 10sec.

After initialization of the internal registers, the program sets peripheral functions and chooses operation mode according to the readings of the mode select rotary switch. A timer interrupt routine is evoked every 16ms and provides communication with the PS2 controller and recording of motor rotation angles, angular velocity and status of switches, joystick outputs and the operation mode. Start and stop signals for recording are activated with the L2 and R2 buttons of the controller respectively.

2)Display and analysis program for recorded data

For rehabilitation staff, in addition to observation of user's performance, quantitative evaluation of their performance is helpful to better judge the effectiveness of training. In this prototype, several objective data are recorded with a memory card. Speed, travel distance and trajectory of the prototype (the middle of driving axle) are calculated by processing these data. Statistical data for inputs such as total number of inputs, maximum on-time, minimum on-time and averaged on-time are also calculated. These show the user's skills in operating the prototype.

III. Field Tests

A. Subjects' profile

There are two objectives for evaluation of the prototype through field tests. One is to observe effects on rehabilitation of users using the prototype. The other is to elucidate problems to improve the prototype. In cooperation with Sagamihara municipal rehabilitation center for children with disabilities (Yoko-en Disabled Citizen's Center), field tests were conducted. As subjects, a 4-year-old boy (subject A) with combined cerebral palsy (GMFCS[11] V, intelligence tested: 1 year old), and an 8-year-old girl (subject B) with combined cerebral palsy (GMFCS IV, intelligence tested: 5 year old) were tested almost once a month for one year. In advance, informed consent was obtained through explanation to the subject B (subject A had difficulty in understanding), their parents and rehabilitations staff.

B. Protocol

Subjects were accompanied by their rehabilitation staff (either PT or OT) on the prototype in the beginning to learn how to move the prototype. The operation mode was set to manual four-switch mode. The maximum speed was 1km/h. During the test, they were encouraged to move on a level (plastic tile) floor in a hall using the push button switches. The first five tests for subject A were conducted on a carpet. The test continued until the staff, noticing his decreased concentration, decided to stop. Subject A used the first prototype only, but there is no big difference with regard to mobility functions.

C. Evaluation

To evaluate their performance, observation by their parents or rehabilitation staff (PT or OT) and video monitoring were employed for upper limb or hand motion analysis and trajectory analysis. As quantitative data, number of inputs and duration of each test were compared.

IV. Results

A. Subject A

Subject A took part in 13 tests in total. After 6 tests, he sat in his seat and got on the prototype. It was difficult to instruct him to set a goal for movement, because of his poor communication skill. For this reason, the rehabilitation staff or his mother stood in front of him and asked him to approach them. He started to push switches by himself. The number of inputs and the durations are shown in Figure 2 and 3 respectively. It seemed he could concentrate on the operation well, after starting to operate the prototype by himself. This progress is indicated by an increased number of inputs. At the 10th and 12th test he could not concentrate due to his physical conditions. He did not learn to turn corners, although he pushed switches for left turn and right turn. He could not continue tests, because he needed surgery for a severed ankle tendon.

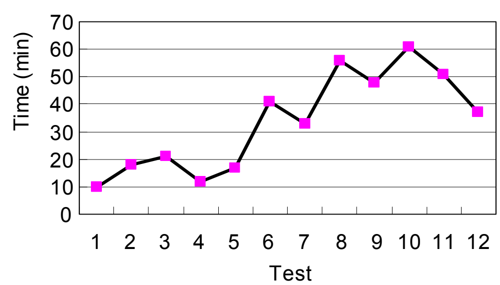

Fig. 2 Test duration

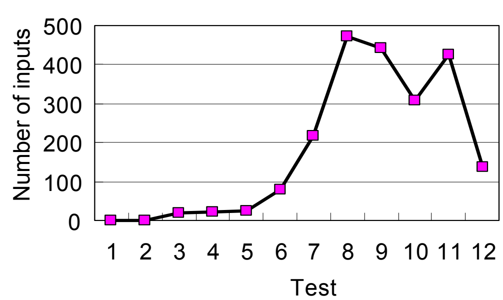

Fig. 3 Number of inputs

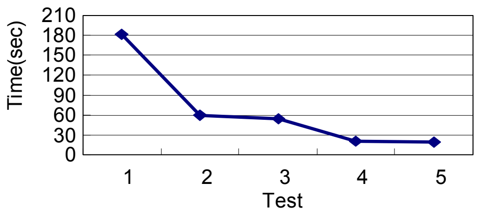

Fig. 4. Time for 5m move

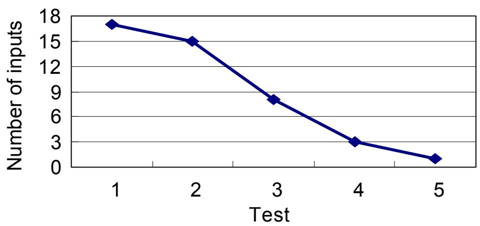

Fig. 5. Number of inputs for 5m move

B. *Subject B*

Subject B took part in 12 tests in total. She could not speak, but understand verbal instructions. Then the rehabilitation staff instructed her regarding temporary goals. After 7 tests, several test courses were set varying the width of the path (2.5-1.5m) with collapsible chairs. The course was 5m long. Two courses were used, one straight, the other L-shaped. She learned how to avoid collision with the chairs or walls. She sometimes moved her arm unintentionally and pushed wrong buttons (synkinesis), but otherwise she managed to control the prototype. She could turn corners by herself. The minimum move time and the least number of inputs for a 5m straight move are shown in Figure 4 and 5 respectively (5 tests) . The values decrease as she acquired skill in operation of the prototype.

V. Discussion

A. *The prototype*

The prototype has semi-automatic operation modes which allow children to experience linear motion or rotation. The effectiveness has not been tested yet. Rehabilitation staff at some institutions suggested one-switch mode would make the prototype follow lines on the level floor while the switch is activated. Although this eliminates the workspace of the prototype, it is good for safety. Speed and acceleration or deceleration parameters are set following ordinary powered wheelchairs, but optimum values for the first experience should be investigated. As a safety measure, wireless switches are not enough. As collision detection, tape switches need to be added.

B. *Field tests*

It is certain that both subjects experienced independent mobility and made great progress in operating skills for the prototype. The goal was different depending on their physical and cognitive conditions. The rehabilitation staff expect that subject B could eventually operate a powered wheelchair in the institution. However, the objective data are limited to performance data. These tests were conducted almost once a month. The learning curve would have been different if they had been conducted more often.

Subjects were limited to children with cerebral palsy. The prototype should be tested on children with other diseases such as spinal muscular atrophy or spinabifida.

VI. Conclusion

In order to provide non-ambulatory children with opportunities to experience independent motions, a prototype cart was developed. Due to the low floor of the cart, users can get on and operate in various positions with a variety of input devices. It can record state of the cart and operations of the user for performance evaluation. The prototype was tested on two children with combined cerebral palsy for one year. Both achieved independent motions by themselves and made great progress in operation skills.

Programs to encourage children with disabilities of various severities to experience motion and acquire operating skills are yet to be developed; they could make good use of recorded performance data obtained through this study.

References

[1] Network for Spinal Muscular Atrophy (NESMA) http://www.sma.gr.jp/english/english/index.html (accessed Apr.23 2009)

[2] T. Inoue, "Independent mobility by electric wheelchair and psychological development , " *Rehabilitation Engineering*, vol. 16, no.4, pp. 8–12, 2001. (in Japanese)

[3] T. Inoue, M. Sakai, H. Iwai, "Practice of technological support and possibility of electric wheelchair , " *Rehabilitation Engineering*, vol. 21, no.2, pp. 91–95, 2006. (in Japanese)

[4] C. Butler, "Physical Medicine and Rehabilitation Clinic of North America. Augmentative mobility Why do it?, " *Pediatric Rehabilitation (ed. by Jaffe KM)*, vol.11, pp. 801-816, 1991.

[5] C. Butler, "Effects of powered mobility on self-initiated behaviors of very young children with locomotor disability, "*Developmental Medicine & Child Neurology*, vol.28, pp. 325-332, 1986.

[6] A. Kakimoto, H. Yura, A. Odaki, S. Suzuki, Y. Sekiguchi, F. Matsuno, "Development of a cart for independent mobility assistance for non ambulatory infants," *Bull. Polytechnic University*, Vol.36A, pp187-195, 2007. (in Japanese)

[7] G. Kinoshita, M. Sakai, Y. Nakamura, T. Inoue, "Development of an Evolving Electric Powered Wheelchair for Children with Disability." Proceedings of the Welfare Engineering Symposium 2006, PP. 43-44, 2006. (in Japanese)

[8] S. Kinoshita, Y. Kawasaki, "Development of Rehabilitation Standingboards for Physically and Mentally Challenged Children to Promote Their Independence and Fun Activities." *Proceeding of Rehabilitation Conference 2002*, pp. 89-92, 2002. (in Japanese)

[9] S. Kodama, K. Suzuki, M. Ariyoshi, "Trial manufacture of electric wheelchair with seating chair for congenital amelia child", *PO Academy Journal,* vol.11, no.1, pp. 60-66, 2003. (in Japanese)

[10] K. Jaffe, C. Butler, R. Hays, D. Everard, "An Innovative Motorized Wheelchair for Young Disabled Children." ICIB, vol.21 no.3, pp. 46, 1986.

[11] R. Palisano, P. Rosenbaum, S. Walter, D. Russell, E. Wood, B. Galoppi B, "Development and validation of a gross motor function classification system for children with cerebral palsy." *Developmental Medicine & Child Neurology,* vol.39, pp. 214-223, 1997