Supporting Technology for Wheelchair Users
Intuitive Interface and Step Climbing Assistance

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Abstract. This paper introduces the two types of supporting technology for wheelchair users. One is the intuitive interface for electric wheelchair user. The other is step climbing mechanism for manual wheelchair users. In order to realize intuitive interface, we adopt to use human body motion interface. From the experiment, it turned out that proposed interface has a potential for providing intuitive operation. For manual wheelchair users, we propose the assistive caster unit for step climbing. This Caster unit has two functions, one is the assistive plate and the other is lock function. The assistive plate makes easy step climbing. The lock function enables to climb a step form oblique approach. For the experiment, the proposed caster unit could reduce user's driving force, namely it could assist manual wheelchair users.

Keywords: Human Body Motion Interface, Intuitive, Step climbing, Caster.

1 Introduction

This paper introduces two supporting technologies for wheelchair users. One is the intuitive interface for electric wheelchair. The other is the caster unit to assist a step climbing for manual wheelchair users.

There are two types of wheelchair which are electric and manual drive, and they are typical assistive apparatus. The wheelchair has not only complement functions of mobility but also means of assisting the human activities and social participation of user. For example, In order to save user's physical power as much as possible, the wheelchair takes charge of all mobile functions. Then preserved user's physical power can be allotted to the user's activity such as work, leisure and sport after locomotion, then user can receive the vitality and enjoyment. The locomotion is no more than means for obtaining enjoyment.

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The locomotive assistance by wheelchair, which does not spend user's physical energy, can contribute to enhance the quality of life and enjoyment.

Thus the wheelchair is the assistive apparatus for not only complementing user's mobile functions but also enhancing user's quality life by promoting user's activity and participation. The components of the human life which is shown by ICF (International Classification of Functioning, Disability and Health)[1] also suggest that concept.

For this concept, it is important to focus the design which does not require waste power or energy of user. The key points are the intuitive interface in case of electric wheelchair, and mechanical system to reduce user's driving power in case of manual wheelchair. Therefore this paper considers following issues. Here, this paper targets the users who can move their arms and keep their upper body posture arbitrarily.

(I) What is the intuitive interface design for electric wheelchair?
(II) What is mechanism to reduce user's driving power?

Regarding (I), the interface, which uses natural body motion caused by voluntary motion, is proposed in section 2. For (II), we indicate the caster which can reduce the driving power and can be replaced from conventional wheelchair caster without any modifications at mainframe of wheelchair in section 3.

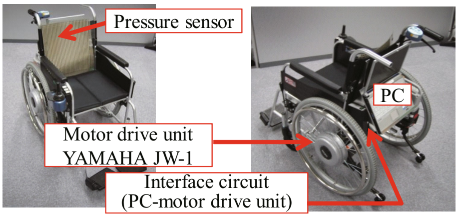

Fig. 1. The overview of the prototype

2 Human Body Motion Interface

In order to utilize the electric wheelchair as an assistive apparatus, its interface should offer the intuitive control. Non-intuitive interface gives stress to the user[2]. If the locomotion, which is essentially means, becomes the purpose, and then the motivation of user for a certain activity is decreased. The conventional electric wheelchair interface is the stick controller. For using the stick controller, user needs to estimate the motion of wheelchair and combine some wrist motions. Therefore stick controller is not always intuitive, because it requires logical combination of estimation and motion. Furthermore, it requires complex wrist movement that becomes difficult with age[3] and may result in inadequate control leading to accidents.

Therefore it is useful to consider an interface that uses a body part other than the wrist without need for complex movement. In order to realize this intuitive interface, we focus on the natural body motion which comes from voluntary motion[4]. It is considered that this natural motion is linked to intention of actions. Therefore, we think that the intuitive interface is realized by using natural body motion. We call this interface as Human Body Motion Interface(HBMI), and adopt it for controlling an electric wheelchair[5](Fig. 1).

2.1 Control of the Electric Wheelchair

We made a prototype by using human body motion interface. In this section, the outline of the system and control scheme is presented.

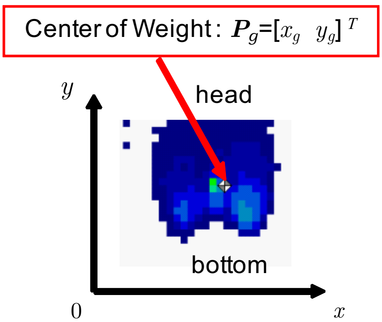

Fig. 2. The coordinate of the center of weight of pressure on the backrest

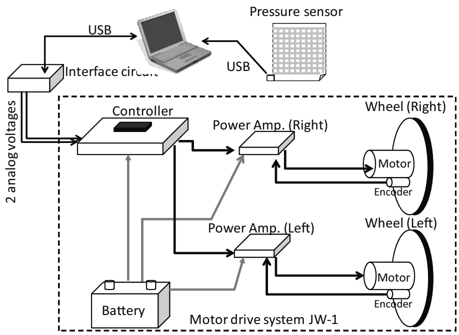

Fig. 3. Proposed system configuration

System Configuration. The center of weight on the pressure distribution on the backrest(Fig .2) is used for control input to the interface. The system configuration is shown in Fig. 3. The main elements of this system are motor drive unit, pressure sensor and PC. BPMS (Tekscan Inc.) is adopted as a pressure sensor, YAMAHA JW-1 is used as motor drive unit. The control unit of JW-1 receives two instruction voltages which are back-forward and left-right direction from PC, and allots adequate voltage to left and right wheel motor. PC has both roles which are main controller and collecting data from pressure sensor. PC gives the drive voltage to each wheel based on the pressure information. Fig. 1 is the overview of the electric wheelchair controlled by HBMI.

Control Scheme. Proposed system uses the center of weight (Fig. 2) as a change of pressure distribution caused by body motion. Since the interface of JW-1 is two voltages, the position of center of weight is converted into two voltages. Then body motion is connected with the motion of wheelchair. The following procedure is control scheme.

1. The initial position of the center of weight $\boldsymbol{P}_{g0}$ is recorded when the operation starts.
2. The instruction voltage is calculated by following equation.

$$\boldsymbol{V} = \boldsymbol{A}(\boldsymbol{P}_{g0} - \boldsymbol{P}_g) \tag{1}$$

   Here,
   $\boldsymbol{P}_g$: Position of the center of weight
   $\boldsymbol{P}_{g0}$: Initial Position of the center of weight
   $\boldsymbol{A}$: Transfer matrix from position to voltage
   $\boldsymbol{V}$: Instruction analog voltage

3. The instruction voltage is sent to the motor drive unit through the interface circuit.

The wheelchair is controlled by above-mentioned method. Fig. 4 shows the test run result. The subject could drive the wheelchair on the figure 8 course layout. As the test run result shows, user can control the wheelchair.

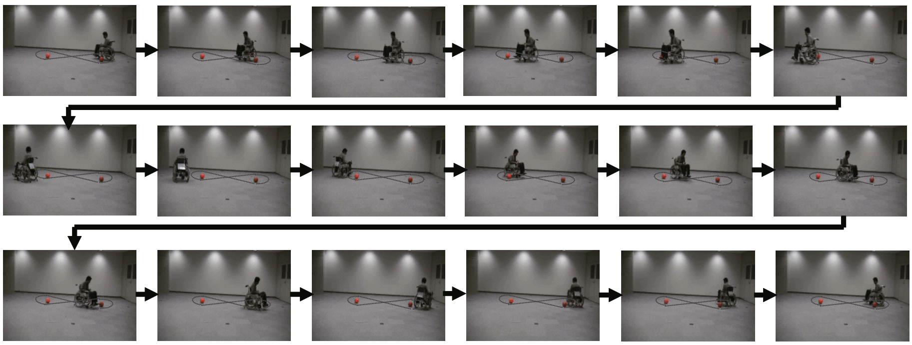

Fig. 4. The test run, on figure 8 course layout

2.2 Evaluation

Experiment was conducted by using 10 subjects to evaluate feeling of operation by utilizing SD method. For 10 subjects, this experiment was the first time to ride a proposed system. Subjects run on the indoor floor, which size is 4m X 4m, in 5 minutes. At this time, there is no restriction for the trajectory, namely, the subjects can run freely in 5 minutes. After that, subjects filled in the questionnaires, and feeling of HBMI was evaluated by SD method. Fig. 5 indicates the answer of each subject. For this figure, Subject A, E, D have the impression of "intuitive and easy operation" rather than the impression "the intention matches the motion" because their questionnaire results are plotted in fourth quadrant. Subject B has the impression of "the intention matches the motion" rather than "intuitive and easy operation" because his answer is plotted in second quadrant. The impression of the subject C, F, G, I and J is

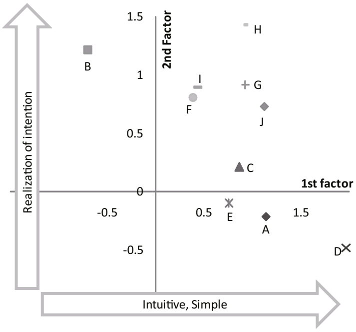

Fig. 5. Factor score

both "the intention matches the motion" and "intuitive and easy operation" because their answer are plotted in first quadrant. Therefore it turned out that HBMI realizes intuitive operation and conformity with the intention although there are differences of impression among the subjects. Thus it was confirmed that HBMI has a potential to provide intuitive operation, and it is the one of the answer for the issue (I) mentioned in section 1.

3 Assistive Caster Unit

One of the main physical loads for manual wheelchair user is driving wheels. User has to drive main wheels by arms whenever he/she wants to move. In particular, in case of uneven road such as stair or gap, user is required to generate more driving forces compared to flat road. Reducing the driving forces in such case contributes to relieve users of their physical burden. That may bring to increase the quality of life of wheelchair users. Therefore, this section introduces the caster unit(Fig. 6 and 7) for assisting the step climbing.

This caster unit also provides easy step-climbing including oblique approach, thus required driving torque for step climbing is reduced comparing with the conventional caster. For this feature, the two functions have been proposed. One is the assistive plate to enlarge the caster radius imaginarily. The other is a lock function on a caster rotation around yaw axis, which enables easy step climbing with oblique approach. Moreover, this unit is easily replaced with the conventional wheelchair caster.

3.1 Key Functions

The problems in case of step-climbing are following two points.

Problem 1) The climb-able step height is limited by the radius of wheel
Problem 2) The driving force is divided in case of oblique step climbing, because the yaw axis of caster rotates when the caster faces the step.

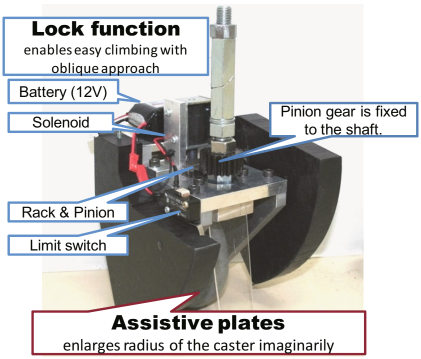

Fig. 6. Proposed Caster unit

Fig. 7. Wheelchair with caster unit

Problem 1) is that: The space between wheelchair frame and footrest where the wheelchair caster is attached is limited, and the caster is designed so as to be installed in this small space. Therefore the caster diameter should be small compared with it of main wheel. Generally, the climb-able step height is less than 1/3 of its diameter for conventional wheel. Thus in case of climbing a 30-40 mm step, users need much power, and have to change the center of weight of his/her body.

Problem 2) is that: In case of oblique step climbing (Fig.8(a)), the yaw axis rotates due to the caster dynamics(Fig.8(b)). For this yaw axis rotation, driving force which is generated by the user is divided into two directions: "moving direction (parallel direction to the step)" and "right direction to the step". The only the force of "right direction" is effective for step climbing. The force "moving direction" is not used, namely the user's force is exhausted. Therefore it is difficult to climb a step or much power is required(Fig.8(b)).

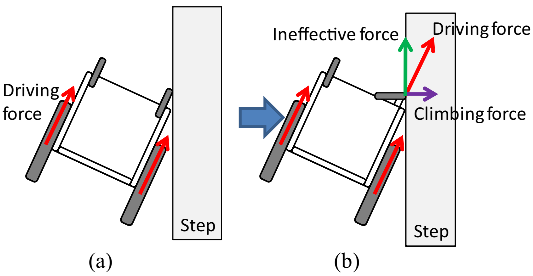

Fig. 8. Driving force in case of oblique approach to a step

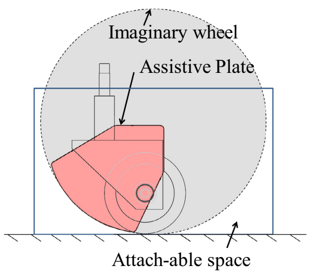

Fig. 9. Assistive plate makes imaginary big caster in the confined space

In order to solve these problems, we propose following two functions

1. Enlarge the radius of caster wheel as possible in the confined space shown in Fig. 9.
2. Lock-function to fix the yaw axis rotation of the caster in case of oblique step climbing.

Assistive Plates. The radius of assistive plate is 123mm. The assistive plates rotates as same as general wheel when the plates touch the step. The assistive plate is not a complete circle, but a sector. The arc part of the assistive plate touches the edge of the step. And it rotates as the same manner of genera wheel rotation. The assistive plates have to be equipped with righting moment force at its rotational center, in order to return the plate in the initial position. For this moment, the torsion spring is attached to the rotational center of the assistive plate.

Lock Function. The role of lock function is to fix the yaw axis rotation of the caster in case of oblique step climbing. The lock function is composed by the solenoid, rack and pinion gear, and limit switch. Fig. 10 is a lock function mechanism. When the assistive plates touch a step, the limit switch is turned on. And then the solenoid is enabled and the rack gear is lifted up, because the rack gear is connected to the output shaft of the solenoid. Then the rack and pinion gear are engaged, and the caster yaw rotation is locked.

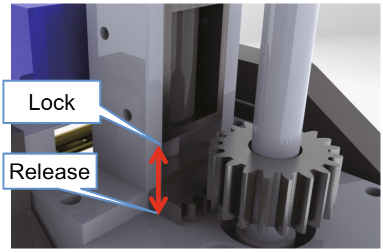

Fig. 10. Lock function mechanism

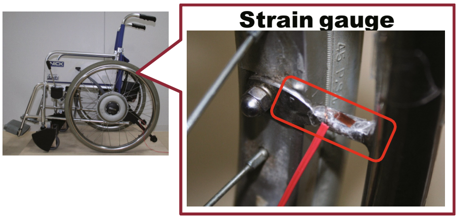

Fig. 11. The attached strain gauge

Table 1. Strain at the root of handrim

Step Height [mm]	Disable Lock Func. Strain[10^{-6}]	Enable Lock Func. Strain[10−6]
10	51.5	42.5
20	78	37.5
30	X	38.5
40	X	68

3.2 Evaluation

In order to verify the efficiency of proposed caster units, we measured the strain at the attached point of hand rim to the main wheel by using strain gauges (Fig. 11).

The one of the results is shown in Table 1. In this table, gXh indicates that wheelchair could not climb a step. It turned out that driving force is reduced by using lock function and assistive plate.

4 Conclusion

This paper introduced the two types of supporting technology for wheelchair users. One was the intuitive interface for electric wheelchair user. The other was step climbing mechanism for manual wheelchair users.

The wheelchair is the assistive apparatus for not only complementing user's mobile functions but also enhancing user's quality life by promoting user's activity and participation. For this concept, it is important to focus the design which does not require waste power or energy of user. The key points were the intuitive interface in case of electric wheelchair, and mechanical system to reduce user's driving power in case of manual wheelchair. Therefore this paper considered following issues.

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