DEVELOPMENT OF THE OMNI-DIRECTIONAL WHEELCHAIR FOR OFFICE WORKS

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This study develops a new omni-directional wheelchair for handicapped persons working in the office. We consider that fully holonomic motion is not necessary. Thus, the developed omni-directional wheelchair has two omni-wheels for rear wheels and two casters for front. Users move by grasping desks, bookshelves and other furniture, for moving in a small area near the desk in the office, with this omni-directional wheelchair. In other places, for transferring passageways, users drive by both-hands or electric motor.

To investigate the effects of the developed omni wheelchair, the time required to move 1[m] lateral side were measured ten times. The results were 11.6 ±0.7sec (standard wheelchair), 7.1±0.5sec (omni wheelchair), and 4.6±0.3sec (caster chair). Omni-directional wheelchair reduces the time about 39% compared with the standard wheelchair. There was a significant difference ($p<0.001$) between these two groups, and these results suggested that the omni-directional wheelchair was practical for handicapped people in office works.

Key words: Omni-directional, Wheelchair, Assistive Technology, Welfare, Office work

1. INTRODUCTION

1.1 The environment of wheelchair-users

In order to live a useful life, improvements of the Quality of Life (QOL) is very

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important, and those people who positively participate and work in the society have increased. Therefore, the infrastructure for handicapped people should be arranged, for instance, handrails, wide space and getting rid of level differences. However, there still remain such problems as the stairs in the stations for the wheelchair-users and handicapped people. The office environment of wheelchair-users also has some problems. In this study, an omni-directional wheelchair is developed to support the office work and improve the efficiency of the work by wheelchair users.

1.2 Differences between wheelchair-users and healthy workers in office works

We have to consider the inconveniences and disadvantages for wheelchair-users in the office, before developing a wheelchair for office works. Problems are summarized as follow;

(1) Seating and tiredness

(2) Mobility and maneuverability

- Getting over the difference in level, ramps and bumps
- Moving, turning and passing each other at small spaces
- Lateral movement
- Low efficiency of the work

The problems of wheelchair-users are divided into (1) Seating and tiredness and (2) Mobility and maneuverability. The problems of (1) are very important to consider, but it is not dealt with in this paper. We emphasize only the (2) problems, because the aim of this study is to improve the mobility and maneuverability of wheelchair and to support working wheelchair-users.

As is well known, it is impossible to get over level differences, steep ramps or large bumps by wheelchairs. Wide space is required for transfer by wheelchair, because narrow passageways and complex furniture arrangements in the office prevent them from transferring. A space of about 1[m] × 1[m] (the width × depth) at a minimum is needed for turning of the wheelchair, and about 1.3[m] width for passing each other. When they enter a blind alley for their business, they have to turn before they return the passageway. If the blind alley is very narrow, they have to return the passageway in reversing. Most wheelchairs cannot move sideways for a structural restriction. When users want to slide 1[m] laterally, they have to do the "switchback motion", so they need a wide space and time. These disadvantages decrease the efficiency of their work. Therefore users demand to improve the mobility of wheelchairs[1].

Normal workers can get over the difference in level, step over bumps and move to narrow space easily in the office, because they can walk on their feet. Concerning lateral movement near the desk, normal workers move around easily near the desk by caster chairs. Although normal workers can transfer any directions in a second by caster chair, wheelchair-users have to do “switchback motion” for lateral movement. So if wheelchair can move like caster chair, the efficiency of the work by wheelchair users will be improved remarkably. Therefore, the purpose of this study is a development of an Omni-directional Wheelchair for office work, to support the performance of handicapped people working in the office.

2. CONCEPTS FOR DEVELOPMENT

2.1 Users and purposes

Users of this omni-directional wheelchair are assumed to be healthy in their upper extremity and be able to use manual wheelchair (both-hands drive). The developed omni-directional wheelchair can only be used for deskwork in the office and indoor of the workshop.

2.2 Demands for the wheelchair

Basic performances requested for this omni-directional wheelchair are the following three points. The omni-directional wheelchair has enough ability for transferring to dining room and restroom in the workshop, so it has same functions standard wheelchairs have. In addition, the function to move freely as the caster chair is necessary for the deskwork. Furthermore, the price of this omni-directional wheelchair must be low cost. Some electric-motor-controlled omni-directional wheelchairs have already been commercialized. But they are not popular in the office, because almost are expensive. We try to keep the cost to one of fifth of existing omni-directional wheelchairs.

The proposed omni-directional wheelchair has to satisfy these three demands, but it needs not the full holonomic function. The omni-directional wheelchair should achieve as holonomic in only small spaces. In other places, it acts like normal wheelchair or normal electrical wheelchair. Therefore, the omni-directional wheelchair we developed in this study has two omni-wheels for the rear wheels and two casters for the front. Users move by grasping desks, bookshelves and other furniture, for moving in a small area near the desk in the office, with this omni-directional wheelchair. In other places, for transferring passageways, users drive by both-hands or electric motor.

2.3 Mechanism for omni-directional movement

Methodologies of omni-directional movement have been discussed in the field of mobile robot[2]-[5]. Several mechanisms already developed as follows;

(1) Omni-directional Wheel Mechanism [6],[7]

The omni-wheel has many barrels on circumference of the wheel as Fig 1-(A). The omni-wheel rolls around own axis like a normal tire. In addition, the barrels allow the motion perpendicular to the rolling direction. Therefore, the omni-wheel enables to move to any direction. In the field of the omni-directional mobile robot, the omni-wheels are arranged under the body of the robot like Fig.1- (B), and all wheels are driven by computer-controlled motors. This omni-wheel mechanism has such difficulty as the following. The rotation speed of the wheels must be is controlled exactly, so the controller becomes complex.

(2) Multiple Active Caster Mechanism [8]

An outline of multiple active caster mechanisms is shown in Fig.2 – (A), and Fig.2 – (B). This mechanism realize omni-directional movement by controlling the steering angle and the rotation speed of all wheels. This mechanism needs additional actuators for driving and steering.

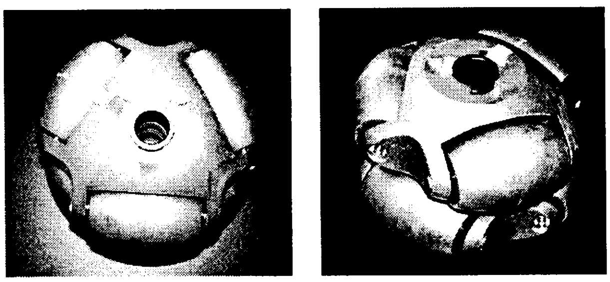

Fig 1 – (A) An omni-wheel.

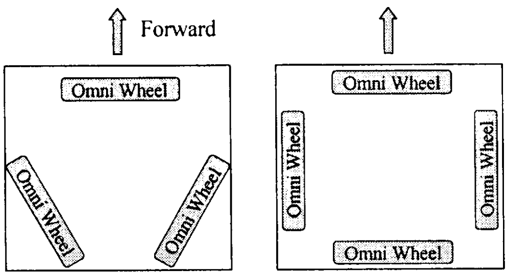

Fig. 1 – (B) Arrangements of the omni-wheels for omni-directional mobile robots.

(3) Ball Wheel Mechanism [9] - [11]

This mechanism adopts a ball for a wheel, and the structure of this is converse to the *mouse* of PC. The small propulsion force and the low ability of moving on a step are defects of this mechanism.

(4) Orthogonal Wheel Mechanism [12] - [14]

Orthogonal wheel mechanism is shown in Fig. 3. Orthogonal wheel mechanism also needs more actuators than its own degrees of freedom.

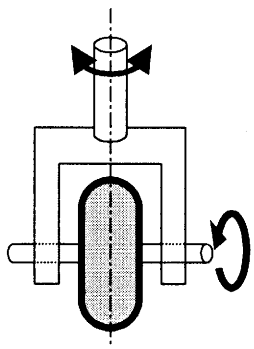

Fig. 2 – (A) The multiple active caster mechanisms.

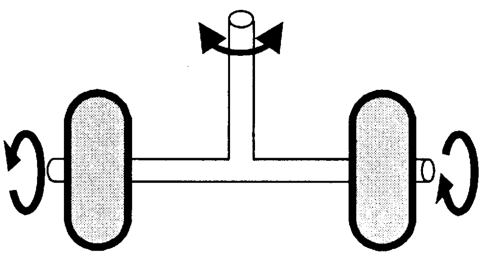

Fig. 2 – (B) The multiple dual active caster mechanisms.

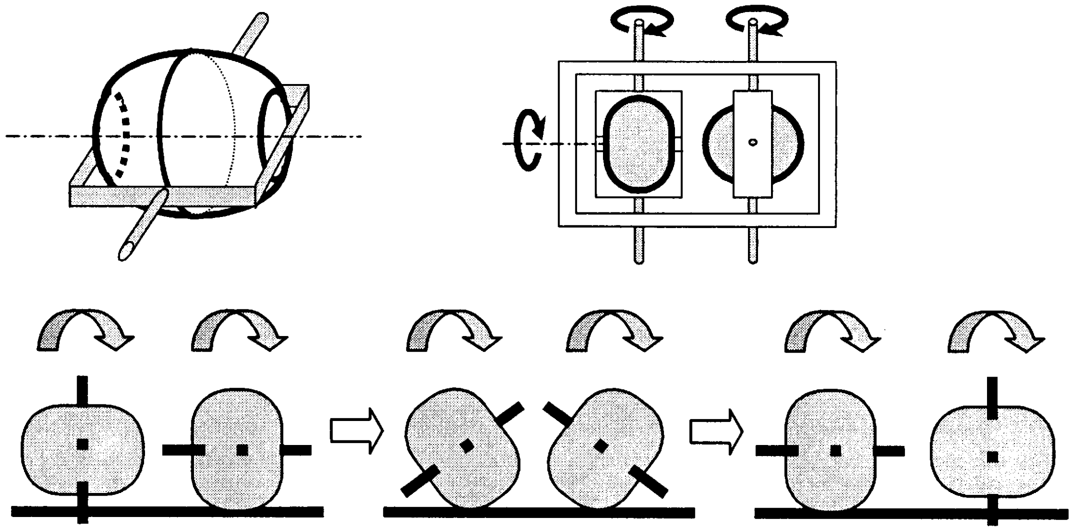

Fig. 3 Orthogonal Wheel Mechanism.

3. SPECIFICATIONS OF THE WHEELCHAIR

Theses mechanisms we described above agree with all directional transfer, but they also have defects. The performance we required of this wheelchair was to realize same mobility as the standard wheelchairs. The ball wheel mechanism, orthogonal wheel mechanism, and normal arrangements of the omni-wheel for mobile robot have not enough ability to move on a bump. The multiple active caster mechanism, ball wheel mechanism and orthogonal wheel mechanism cannot satisfy the cost requirement. Since these mechanisms were complicated and need complex controllers to drive the wheels.

If we restrict the motion to front-back direction for getting over the level difference, omni-wheel mechanism can be used. Therefore, we proposed a new mechanism for omni-directional wheelchair; two omni-wheels are placed with the rear wheels of standard-type wheelchair, and two front casters remain as they are. This style needs not complex controller, so it allows the low cost, and of course it realizes all directional movement. The omni-wheel made for the rear wheel of the wheelchair is shown in Fig. 4. The barrels are placed in dual-row mutuality in the wheel, in order to contact to the ground at least one barrel, as shown in Fig. 4. These barrels are made of the resin.

This study develops two types of omni-directional wheelchairs, as manual drive and motor drive. For driving of manual type in passageways, users handle the both side of hand rims. For driving of the motor type, users operate the joystick.

The front and lateral view of the motor drive type wheelchair are shown in Fig. 5-(A) and Fig.5- (B) respectively. However, in this figure, a joystick is not mounted on the body of the wheelchair. The photographs show this omni-directional wheelchair

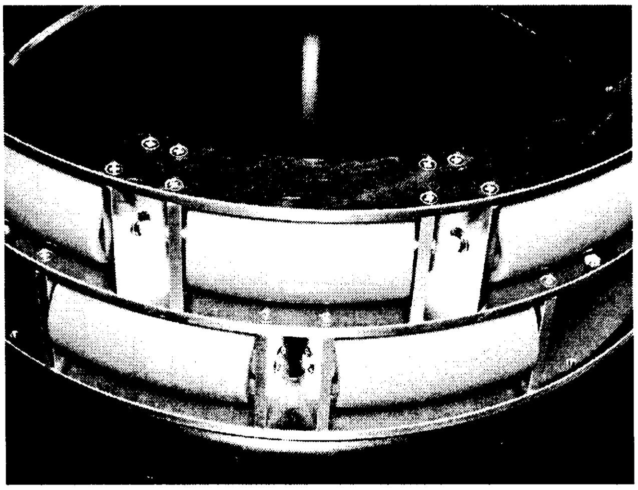

Fig. 4 The rear wheel of the wheelchair using dual-row omni wheel.

standard-type wheelchair. Electrical machinery and apparatus such as motor, battery and amplifier as drive-unit are put under the seat.

Two of electrical motors (Oriental Motor Co., AXH450K, 50W) are installed, and two 12V batteries are connected in series, and 24V is obtained. Though the drive unit as two of 50W motors is smaller than power consumption of standard electric wheelchair, it seems to have enough power, for the service space of this wheelchair is limited to the workshop, and there are not many slopes. And reduction of the machine weight allows a small-size battery. Timing belt and timing pulley transmit the torque from the motor.

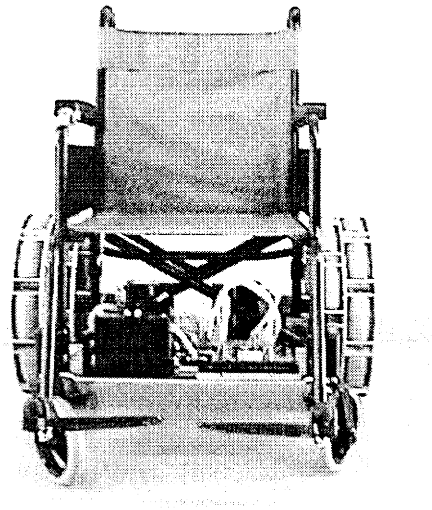

Fig.5 − (A)

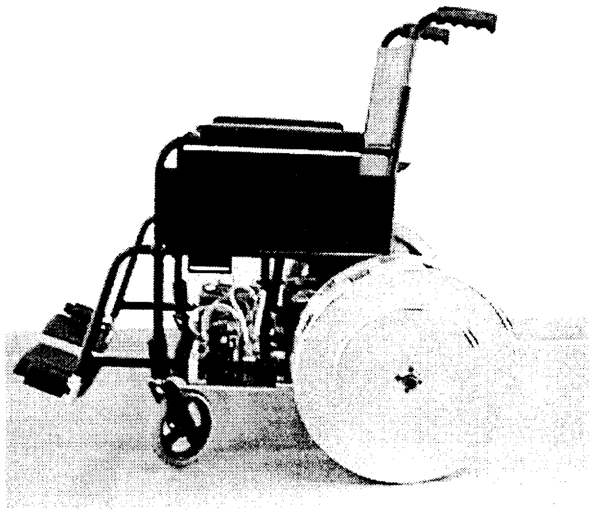

Fig.5 − (B)

(A): Front view, (B): Lateral view of the omni-directional wheelchair (motor drive type).

Table 1 Specification

Outsize (Length x Width x Height)	930x740x830 mm
Weight of the main body	41.4 Kg (battery 4.9kg are removed)
Seat (Width x Depth x Height)	400x410x400 mm
Wheel diameter (Front, Rear)	150, 400 mm
Maximum speed	4.8 Km/h
Width of an omni-wheel	130mm
The number of barrels	20 /each wheel
The diameter of a barrel	50mm (Maximum)

The main specifications of the omni-directional wheelchair (motor drive type) produced in this study are shown in Table 1. The outside dimension is 930 x 740 x 830[mm] (Length x Width x Height), weight is 41.4kg (battery 4.9kg are removed), the seating surface is 400 x 410 x 400[mm] (Width x Depth x Height), wheel diameter is 150 / 400[mm] (front wheel / rear wheel), and practical maximum speed is 4.8km/h. Though the developed omni-directional wheelchair is heavy, it does not hinder the research purpose; it is made for the utilization in the workshops space, and not for going up and down to get on buses or trains. Furthermore, the weight is not unreasonable, since standard wheelchair weighs over 10kg, and the main bodies of marketed electric wheelchair weighs 40～60kg.

Front view and lateral view of the manual type of omni-directional wheelchair are shown in Fig. 6- (A) and Fig. 6- (B), respectively. The omni-wheels are placed under the seat, to match the Japanese Industrial Standard (JIS). But, users cannot handle the hand rims fixed on the wheels, because two rear wheels are placed under the seat. For the adaptation of this problem, hand rims are set independently of the wheels. The torqueses of the hand rim are transmitted by sprockets and chain to rear wheels. The main specifications of the manual omni wheelchair are shown in Table 2.

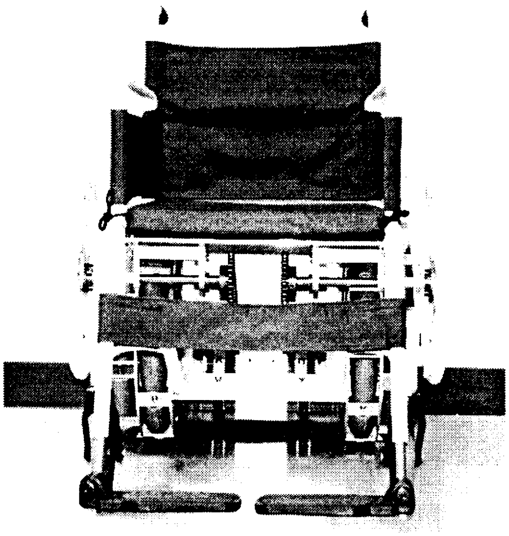

Fig.6 –(A)

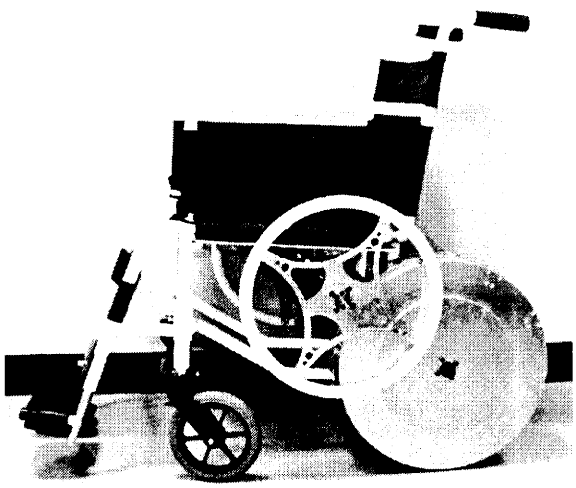

Fig.6 –(B)

(A): Front view, (B): Lateral view of the manual type omni-directional wheelchair.

Table 2 Specification of the manual type omni-wheelchair.

Outsize (Length x Width x Height)	980x645x840 mm
Weight of the main body	43 Kg
Seat (Width x Depth x Height)	400x410x480 mm
Wheel diameter (Front, Rear)	150, 400 mm
Width of an omni wheel	130mm
The number of barrels	20 /each wheel
The diameter of a barrel	50mm (Maximum)

4. METHOD OF PERFORMANCE TEST

The following was investigated to examine the characteristic and failure of the wheelchair for the office produced in this study.

(1) The Time for the lateral transfer

The lateral transfer of interval 1[m] was considered as the usual transfer in the deskwork, from the desk to the desk. We measured the time required for this operation by using standard-type wheelchair, caster chair, and manual type omni-directional wheelchair.

An adult male, who had experience of utilizing the wheelcjair over 6 months, tested each operation. In the case of the lateral motion using standard-type wheelchair, participant did the "switchback motion"; at first moved to backward, turned the direction, and then went forward to destination, like Fig. 7. On the transfer using the omni-directional wheelchair, participant moves by grasping the office desk. In the action by caster chair, participant also grasped the office desk for moving as same as the case of omni wheelchair, but the transfer in kicking the floor on feet was avoided. On the transfer of the standard-type wheelchair, in order to examine the effect of the rear space for changing wheelchair's direction, three types of rear space; 1.1[m], 1.35[m] and 1.7[m] were considered. The rear space of the operations by omni wheelchair and caster chair was 1[m], since it was enough to move.

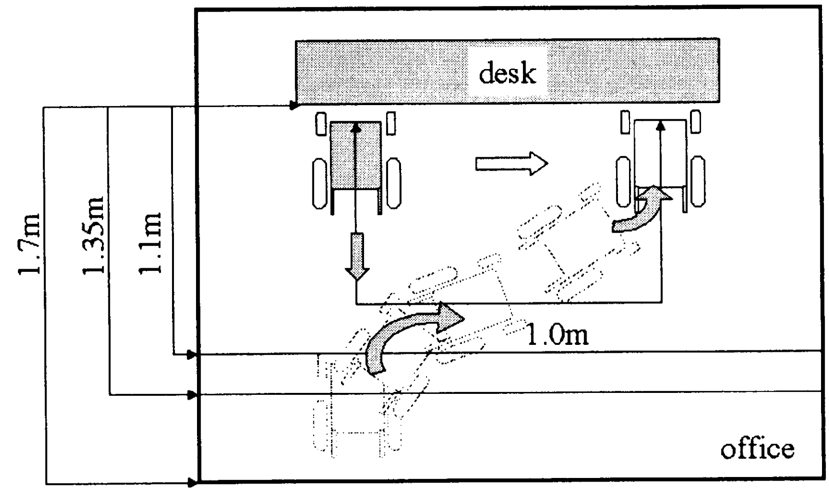

Fig. 7 The course of the "switchback motion" by standard wheelchair for transferring 1m lateral side.

(2) The evaluation of the movement property

Considering the function for the wide area movement (characteristics as an motor drive wheelchair, or manual drive wheelchair), the performances for transfer in workshop, climbing various slope, and the ability to get over difference level were examined.

5. RESULTS AND DISCUSSIONS

(1) The time for the lateral transfer

Time required for lateral motion in each method is shown in the Fig.8; the graph indicates mean value and standard deviation of ten measurements. In the figure "1.1m", "1.35m" and "1.7m" were using the standard-type wheelchair as a classification of the rear clearance, and "omni2" and "caster" correspond the manual type omni-directional wheelchair and the caster chair, respectively.

Lateral motion of 1[m] needs 11.6 ± 0.7(1S.D.) second, the rear space 1.1[m] using the standard-type wheelchair. When the rear space were 1.35[m] and 1.7[m], it was necessary for 9.6 ± 0.5 second and 9.8 ± 0.4 second respectively. In the case of 1.1[m], the time for transferring increased about 21% than the case of 1.35[m], and there was significant difference ($p<0.001$) between these two cases. It also showed the evidence that work efficiency was closely related with the rear space for the operation; "switchback motion", and that poor space prevented the efficiency of wheelchair-users.

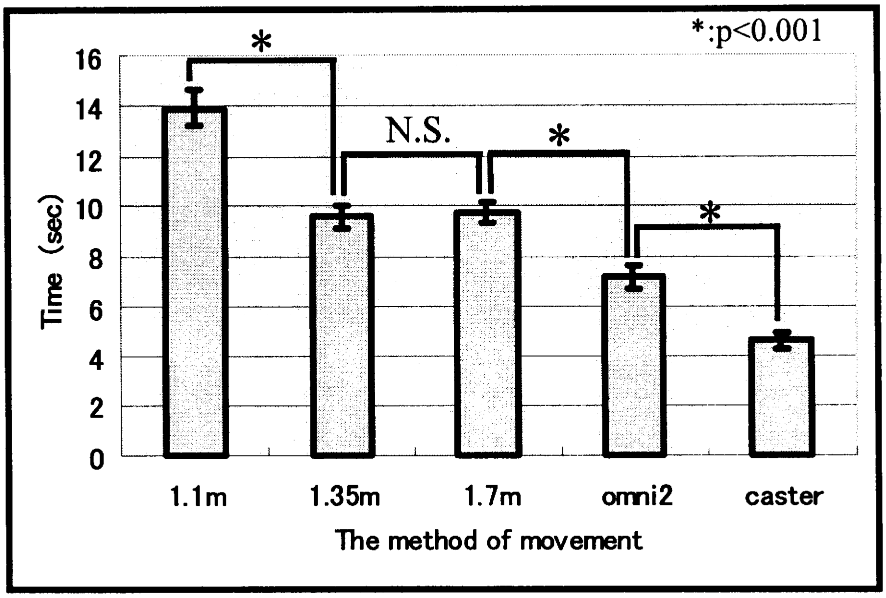

Fig. 8 The time required for transfer to 1[m] lateral side.

There was no significant difference between the case of 1.35[m] and 1.7[m]. Therefore, it can be also guessed that 1.35[m] of the rear space is sufficient for transferring laterally 1[m] by standard wheelchair.

On the other hand, the time were 7.1±0.5 and 4.6±0.3 second, when the omni-directional wheelchair and the caster chair were used. It was considered that the difference of the caster chair and the omni wheelchair was coursed by their inertial mass. The omni wheelchair reduced the time about 26% as comparing with the case of 1.35[m] by the standard-type wheelchair. In the comparison of the omni wheelchair and standard wheelchair with 1.1[m] rear space, the time was reduced about 39%. This seems to be an important result, when the efficiency and usefulness of the office work by the wheelchair user are considered. The results show the effectiveness of the developed omni-directional wheelchair. And we got also enough estimation for transfer to any directions; slide to forward, backward, right and left, whirling on the floor -etc, by grasping the office desks, bookshelves and handrails.

(2) The evaluation of the transport property

The ability of climbing a slope by using motor drive wheelchair was limited about 4° . Driving mechanism caused this limitation. The motor power was not sufficient, and belt drive used wheelchair cannot endure the large torque. However, the available angle of 4° seems to be a sufficient, since it has been limited in the workshop.

In order to investigate the ability of getting over level difference, piled board of the 12[mm] thickness were used as the level difference. 12[mm] height can be got over easily, but 24[mm] was difficult. Standard-type wheelchairs have almost same limitation as the omni wheelchair. The ability of getting over the level difference is very closely related to the diameter of the front casters of wheelchair. The front casters of omni wheelchair have same diameter as the standard-type wheelchair. So it is reasonable to consider that those wheelchairs have same ability of getting over the level difference. The manual type omni wheelchair (manual drive) was also investigated the ability for transferring in the workshop. This manual omni wheelchair could move smoothly as same as the standard type wheelchair.

6. CONCLUSIONS

The purpose of this study is a development of an Omni-directional Wheelchair for office work, to assist the performance of handicapped people working in the office. The developed omni-wheelchair is used only for deskwork in the office and transfer in the workshop. Users of this omni wheelchair are assumed to be healthy in their upper extremity and be able to use manual wheelchair (both-hands drive). In this study we proposed a new omni-directional wheelchair for office works; two omni-wheels are placed with the rear wheels of standard-type wheelchair.

To investigate the efficiency of the omni wheelchair for working in the office, time required for lateral transfer 1[m] was measured. A standard-type wheelchair was also tested for comparison. An adult male, who had experience of utilizing the wheelchair over 6 months, tested each operation.

The results of the time for lateral transfer 1[m] by the standard wheelchair in the conditions of 1.1[m], 1.35[m] and 1.7[m] rear clearance were 11.6 ± 0.7, 9.6 ± 0.5 and 9.8 ± 0.4 second respectively. These results showed that work efficiency was closely related with the space for turning by wheelchair, and poor space lowered wheelchair user's efficiency. The time required by the omni wheelchair was 7.1 ± 0.5 second, and the omni wheelchair reduces the time about 26% and 39% from those of the standard wheelchair with the condition of 1.35[m] and 1.1[m], respectively. We also evaluated the transportability in the workshop, and the results suggested that the omni-directional wheelchair we developed was effective.

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