The 2010 IEEE/RSJ International Conference on
Intelligent Robots and Systems
October 18-22, 2010, Taipei, Taiwan

Power Assist Effects of a New Type Assist Unit in a One Hand Drive Wheelchair with a Triple Ring

Kazuaki Sakai, Toshihiko Yasuda, and Katsuyuki Tanaka, *Member, IEEE*

***Abstract*— We have proposed a one hand drive wheelchair with the original manipulation mechanism and the power assist mechanism. Recently, we have developed a new type assist unit, which had a new ON/OFF mechanism constructed by link and sliding mechanism, in order to realize the sure assist torque transformation. During assist, this new assist unit surely keeps the distance of two rollers, which transfer assist torque to tires. In this paper, first, the assist system, including the proposed assist unit, is explained. Furthermore, by using the prototype of the one hand drive wheelchair, implemented new assist units, the effectiveness of power assist function is confirmed, based on running experiments on the flat ground. In this experiment, we have found the following facts: For the user with enough manipulation ability, the power assist effect is week. On the other hand, for the user with inadequate power, the evident power assist effect is observed.

I. Introduction

BECAUSE of the elderly or the handicapped, some persons have walking difficulty. Using wheelchairs, they are able to get the pleasure and to live a rich life, such that they can move freely. There exist many researches improving wheelchairs [1-3]. In order to improve the mobility of persons who can use only one hand for the manipulation of the wheelchair, for example, due to the hemiplegia, various one hand drive wheelchairs, such as a lever type and a double ring type, are marketed. These equipments are extremely useful and are utilized in various welfare facilities or homes, because these equipments are effective in moving a short distance on the flat ground with comparatively little running resistance. However, in the outdoors, the physical load, on using these one hand drive wheelchair, increases, because there are rough surfaces and slopes. Therefore, we consider that various assist functions, such as power assist function, the reverse prevention function on the upward slope and so on, are required to one hand drive wheelchairs, in order to use it in the outdoors.

Our research group has produced a one hand drive wheel -chair with newly proposed manipulation mechanism and old type assist units, which realize some assist functions [4]. In order to improve the running ability on the outdoor use, we have developed new type assist unit [5]. In this investigation, we implement the assist unit to the one hand drive wheelchair with a triple ring (See Fig.1).In Sec.2, at first, we explain the structure of assist system, including the improved assist unit. New type assist unit is introduced in Sec.3. Furthermore, by the running experiment using the one hand drive wheelchair equipped with new type assist units, power assist effects is verified.

Fig.1. A prototype of one hand drive wheelchair with new assist units

II. Assist System

In order to explain the assist system of our prototype of one hand drive wheelchair, first, we introduce the manipulation mechanism of one hand drive wheelchair with a triple ring, which is in Fig.2. The manipulation mechanism, shown in Fig.2, can realize all operations, such as “turn right”, “turn left” and “go straight” by manipulating a hand rim by right hand only. For example, a right turn hand rim, depicted in Fig.2, is connected directly with the left wheel by an axis, so rotating this hand rim, the left wheel rotates and the wheelchair turns right. A left turn hand rim is mounted on the right wheel, so rotating this hand rim, the right wheel rotates and the wheelchair turns left. Rotating a middle hand rim, at first, a mechanical clutch is operated and right and left wheel unite like a spinning wheel. In this state, furthermore, rotating a middle hand rim, the manipulation torque is transmitted to the both wheels at the same time and the wheelchair goes straight. This manipulation mechanism has the following characteristics. The manipulator's intention, namely, “turn right”, “turn left” and “go straight”, are easily obtained by installing sensors, which observe manipulation torques, to three hand rims. This ability of data acquisition for “the intention of the operator” is useful for realizing assist functions [4]. As mentioned above, in order to get excellent manipulation performance by only one hand, the wheelchair, shown in Fig.2, has the complicated mechanism, which unites

Manuscript received March 10, 2010. K. Sakai is now with Northeastern Industrial Research Center of Shiga Prefecture, Hikone Shiga 522-0037 Japan (phone: 81-749-22-2325; fax: 81-749-26-1779; e-mail: sakai.kazuaki@shiga-irc.go.jp).

T. Yasuda is with the University of Shiga Prefecture, Hikone Shiga 522-8533 Japan (e-mail: yasuda@mech.usp.ac.jp).

K. Tanaka is with the University of Shiga Prefecture, Hikone Shiga 522-8533 Japan (e-mail: k-tanaka@mech.usp.ac.jp).

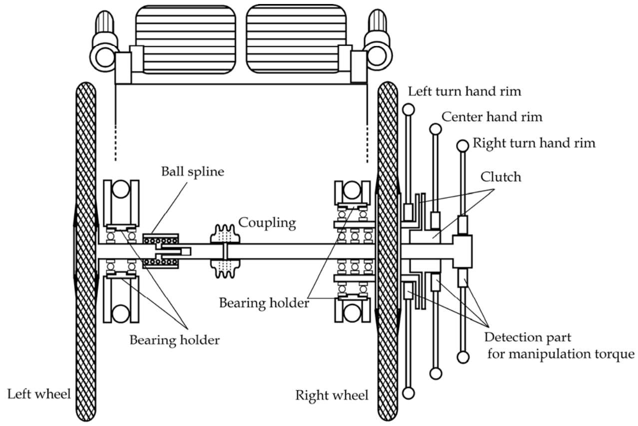


Fig.2. Manipulation mechanisum of one hand drive wheelchair with a triple ring

Table 1 Dimensions of one hand drive wheelchair

Dimension	
Length	850[mm]
Height	760[mm]
Width	670[mm]
Rear wheel (diameter)	600[mm]
Left turn hand rim diameter	520[mm]
Center hand rim diameter	460[mm]
Right turn hand rim diameter	400[mm]
Total mass	38[kg]

wheels or hand rims, locating both sides of the wheelchair, and which contains the detection sensor, sending the manipulation torque information to controller, on three hand rims. Hence, the running resistance is slightly larger than that of usual wheelchair. Therefore, the power assist is useful. The main dimensions of this wheelchair are shown in Table 1.

Fig.3 shows the structure of the assist system, which includes a manipulation mechanism presented in Fig.2 and assist units developed by our research and, furthermore, includes some observation and control devices. “Manipulation torque inputted by using the hand rim” is acquired by the strain gauge mounted on hand rims. The detection range of the manipulation torque is from -60[Nm] (backward direction) to +60[Nm] (forward direction). This manipulation torque changes into the output voltage by using the bridge circuit of strain gauges, whose range is zero[V] (-60[Nm] backward direction) to 5[V] (60[Nm] forward direction). The rotary encoder, installed in right and left wheels, acquires the rotation velocity of right and left wheels. The output of the rotary encoder is input to the FV converter. The output of FV converter for the forward velocity is zero[V] in the case where the forward velocity is zero[m/s] and the output of FV converter for forward velocity is 5[V] in the case where the forward velocity is 2.78[m/s]. The backward velocity is also obtained by using the FV converter for backward velocity.

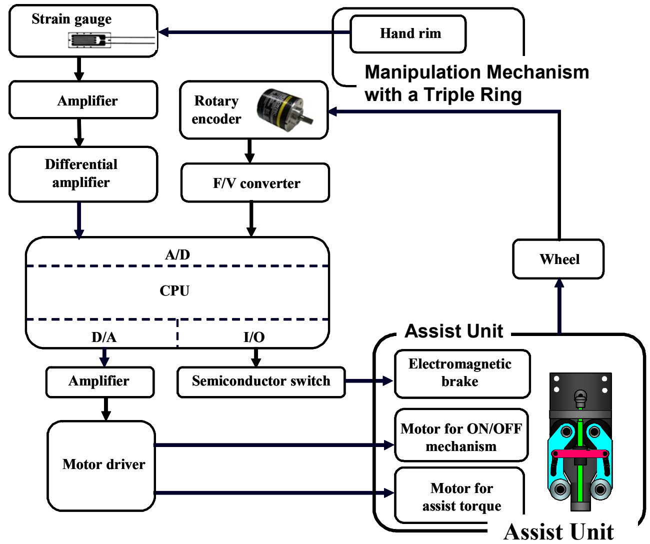


Fig.3. System flow of assist system

The left and right wheels both have these velocity observation devices. Based on these manipulation torques and rotation velocities of left and right wheels, various assist commands are automatically produced by the controller, build on a microcomputer H8/3048. The microcomputer controls the assist torque provided by the motor, ON/OFF mechanism of assist unit and ON/OFF of electromagnetic brake. Because the signal giving manipulation torques and rotation velocities are the analogue voltage, these observation data are acquires through the A/D converter on the microcomputer. Motor drivers, ON/OFF mechanism of the assist unit and electromagnetic brakes are controlled by commands, which are outputted from the D/A converter and the digital I/O ports.

III. Assist Unit

A. Previous Type Assist Unit

As shown in Fig.4, assist units are independently equipped with both wheels. Hence, the DC motor can give the assist torque to both wheels independently. Fig.5 shows the previous type assist unit, which realizes assist functions such as “power assist”, “maximum velocity limiting on the downward slope” and so on. This assist unit is composed of a DC motor (150W), an electromagnetic brake, a stepping motor and so on. The assist torque generated by the DC motor is transmitted to two robber rollers through belt transmission.

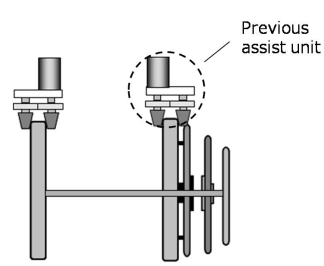
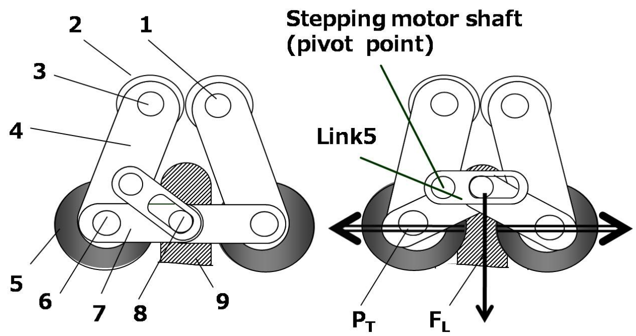
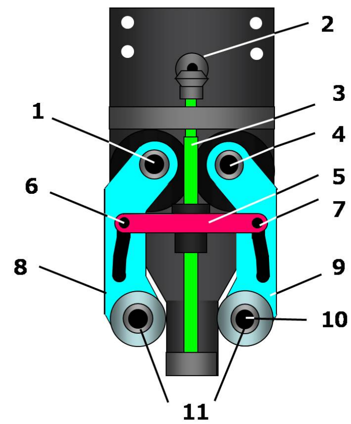


Fig.4. Layout of assist unit



(a) Pull off state of rubber rollers (b) Put on state of rubber rollers
1:Drive follow shaft, 2: Gear, 3: Motor shaft , 4:Link, 5:Rubber roller, 6: Rubber roller shaft, 7:Link, 8:Middle shaft, 9:Tire, P_T: Opposing force of tire, F_L: Pushing force of Link5
Fig.5. Link mechanism in previous type assist unit



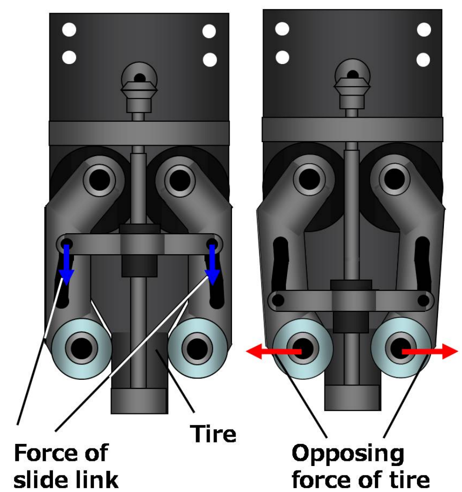
1: Drive shaft, 2: Bevel gear, 3: Ball screw, 4: Drive follow shaft, 5: Slide link, 6, 7: Slide shaft, 8, 9: Link, 10: Rubber roller shaft, 11: Rubber roller
Fig.6. New type assist unit

Two rubber rollers, gripping wheels, transmit the assist torque from the DC motor to wheels. This previous type assist unit has a link mechanism which is shown in Fig.5.By using the link mechanism, which is driven by the stepping motor, when the wheelchair does not need the assist torque by the DC motor or the brake torque by the electromagnetic brake, rubber rollers separate from the wheel, as shown in Fig.5.(a).Hence, the DC motor and rubber rollers don't yield the running resistance. On the other hand, while the wheelchair needs the assist torque by the motor, rubber rollers grip the wheel, as shown in Fig.5.(b).In this previous assist mechanism, in which the stepping motor lifts a middle shaft by turning the link 5, during assist on, the middle shaft receives a downward force from the link 5 (See Fig.5). This downward force is produced by pushing force of the tire to rubber rollers (See Fig.5.(b)).In the previous type assist unit, due to the above mentioned mechanical disadvantage, there exists a case where the distance between rubber rollers spread and the sufficient assist torque dose not transfer to tires from rubber rollers.

B. New Type Assist Unit

In order to solve the disadvantage of the previous type assist units, we newly designed the ON/OFF mechanism of the assist unit, so that the gripping power of roller does not weaken by pushing force from tires. The new type assist unit is depicted in Fig.6.From discussions previously presented, if the distance between two rubber rollers doesn't spread during assist on, the sufficient assist torque, which transfers from rubber rollers to wheels, never weakens. Therefore, we newly design the ON/OFF mechanism of assist unit that, during assist on, the distance between two rubber rollers is fixed.

Of course, to realize ON/OFF of the assist by attaching or removing a rubber roller from the tire, the mechanism, which varies the distance between two rubber rollers is necessary. To realize these demands, we propose the ON/OFF mechanism shown in Figs.6 and 7.The characteristic of proposed link is two flute link and slide link. The position of two drive shafts 1 and 5 is fixed. Two flute links 8 and 9 can rotate around the drive shafts. Slide shafts 6 and 7 are inserted in flutes on flute links. The distance between two slide shafts



(a) Pull off state of rubber rollers (b) Put on state of rubber rollers
Fig.7. Link mechanism of new type assist unit

is fixed by the slide link 5. The position of the slide link changes by the ball screw 3, which is driven by DC motor.

If the position of the slide link is the position shown in Fig.7.(a), then two flute links are open state and rubber rollers does not grip tires. On the other hand, if the position of the slide link is the position shown in Fig.7.(b), then two flute links are close state and rubber rollers grip tires. This is the ON/OFF mechanism of improved assist unit.

The new mechanism has the following characteristics:

1) Stable gripping force of rollers: Opposing force of tire, depicted in Fig.7.(b), never spread the distance of two rubber rollers.

2) Easy attachment of assist unit: Assist unit doesn't change a structure of wheelchair and the attachment of the unit is easy, as shown in Fig.8.

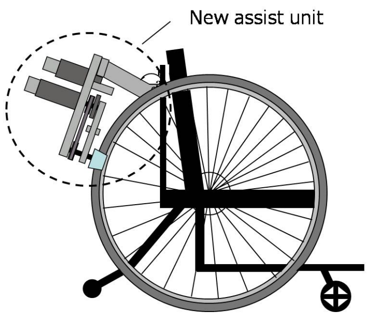


Fig.8. Layout of new type assist unit on wheelchairs

II. Drive Force of Slide Link

A Drive Force of New Type Assist Mechanism

The slide link 5 is driven by the ball screw3.(See Fig.6.) In order to select the ball screw and the motor, which drive the ball screw, we calculate the power which is necessary to move the slide link. By the movement of the slide shaft, the distance of rubber rollers open and close. In Fig.9, F is the force which pushes down a slide link and W is "the opposing force to the rubber roller axis", which receives from the tire. The opposing force W is measured by the load meter as about W=50[N]. Using this opposing force data, we calculate necessary pushing force F. Noting that two flute links are symmetric, we consider the balance of the moment around the drive shaft on the left hand side (See Fig.9). By using symbols represented in Fig.9, and considering the balance of the moment, we obtain the following equation

$$F = \frac{W \cdot A\cos\theta}{x} \quad (1)$$

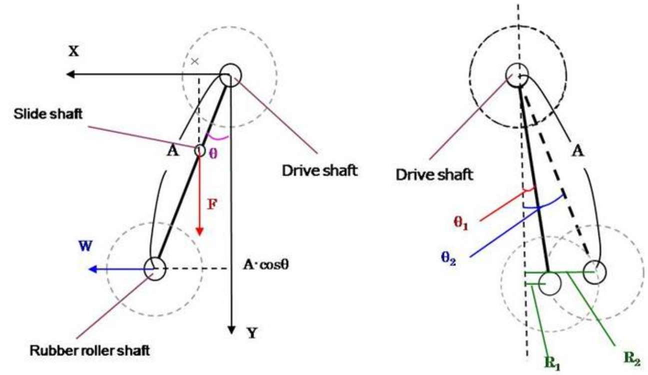
The angles of slide shaft θ_1, in Fig.9, are given by

$$\theta_1 = \sin^{-1}\left(\frac{R_1}{A}\right), \quad (2)$$

where θ_1 is the angle during assist on. The length R_1 is given by

$$R_1 = \frac{l_1 - l_3}{2} = 6.45[\mathrm{mm}] \quad (3)$$

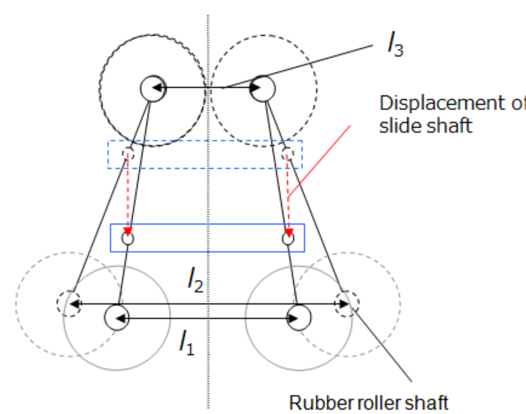
(See Fig.10) In this investigation, we set the distance A as. A=100mm. Substituting A=100[mm] into (2), we obtain θ_1=3.47[deg.]. Finally, substituting W=50[N], A=100[mm], $\theta=\theta_1$=3.47[deg.] and x=20[mm] into (1), we obtain the necessary pushing force F=249[N]. Based on this calculated force, we select the ball screw with the lead 0.2[mm] and DC motor with the output 150[W] (maxon RE40).



(a) Moment balance around drive shaft (b) Position of rubber roller shaft at assist on and off

A : Distance from drive shaft to rubber roller axis shaft
θ : Angle of slide shaft and Y axis,
x : X-coordinate of the position of the slide shaft,
F : Pushing force to slide link,
W : Opposing force to rubber roller from tire
θ_1, θ_2 : Angle of slide shaft and Y axis
R_1, R_2 : X-coordinate of the position of rubber roller shaft

Fig.9. Drive power of slide link



l_1: Distance between two rubber roller shafts during assist on
l_2: Distance between two rubber roller shafts during assist off
l_3: Distance between drive shaft and driven shaft

where l_1=58.9mm, l_2=68mm and l_3=46mm.

Fig.10. Definition of l_1, l_2 and l_3

V. Running Experiment with New Assist Units

In order to show the power assist effect by the new type assist unit, we carried out the running experiments by using the prototype of the one hand drive wheelchair, with and without power assist. By analyzing the obtained data, the decrease of physical load, that the operator feels, is confirmed.

A. Experimental methodology

Experiments were carried out on the flat ground. The operator adds a manipulation torque to hand-rims for the going-straight and runs the distance of 25[m]. We measure the running time of each runs, without and with power assist. In the case of "without power assist", rubber rollers always separate from tires. In the case of "with power assist", by using newly developed assist units, if the operator adds the manipulation torque, then assist torque, generated by DC motors, are added to tires. Note that if the operator removes hand rims and does not add the manipulation torque, then rubber rollers remove from tires and assist units do not yield the running resistance. In this experiment, the assist torque is added only in the case where the operator add the manipulation torque to the middle hand rim, namely, only in the case where the operator rotates both tires by one hand and the wheelchair goes straight. In this experiment, the assist torque are determined by

$$\text{Assist Torque} = 0.5 \times \text{Manipulation Torque.} \quad (4)$$

As shown in (4), the assist torque is proportional to the manipulation torque, which is given by operator. The result of experiments by 9 examinees (healthy men) is shown in Table 2, which shows the running time with physical data of examinees.

B. Effect of power assist

Before evaluating the effect of power assist, we examined the correlation coefficient r of each characteristic-variable, presented in Table 2 and we obtain Table 3. Noting that, based on the theory of the statistical test, the correlation coefficient r between running time without power assist and weight satisfies that

$$r = 0.719 > r(f = 9-2, \alpha = 0.05) = 0.666,$$

therefore there exist the significant correlations between two variables, where f is degrees of freedom and α is the significance level of a test.

Table 2 Results of running experiments

Subject	Weight [N]	Height [cm]	Running time without Power Assist [sec.]	Running time with Power Assist [sec.]
1	539	172	24	24
2	588	172	31	29
3	588	175	24	26
4	637	174	38	35
5	637	180	33	26
6	686	176	37	26
7	706	172	27	24
8	785	179	40	27
9	834	185	39	31

Table 3 Relation between each characteristic value (Value of correlation coefficient: r)

	Weight [N]	Height [cm]	Running time without power assist [sec.]	Running time with power assist [sec.]
Height[cm]	0.741	1		
Running time without power assist [sec.]	0.719	0.626	1	
Running time with power assist [sec.]	0.228	0.255	0.615	1

From Table 3, we obtain that, in case of without assist, the single correlation between running time, which shows the manipulation ability of the user, and the weight is significant. Based on this result, we pay attentions to the relation between the weight of examinee and the running time without power assist and we obtain Fig.11.

Fig.11 shows that, in this experiment, heavy examinees have less manipulation ability. In order to verify an assist effect according to the examinee's ability, the examinees must be specified according to their ability. In this investigation, examinees are divided into three groups with the different ability's level. Namely, based on Fig.11, we construct three groups, represented by Group-F, Group-M and Group-L. Each group is constructed by 3 examinees. Group-F is constructed by examinees with good manipulation ability, namely, by examinees that the running speed is fast (about 1[m/s]) and that the weight is comparatively light. Group-M is constructed by examinees whose weight is middle and that the running speed is also middle Group-L is constructed by examinees whose weight is comparatively heavy and whose running ability is comparatively less. In order to confirm the effectiveness of the above mentioned grouping, the variance analysis of the running time data with and without the assist is calculated. From this variance analysis, with a high significance level (α=0.01), the difference of divided groups is confirmed. Therefore, assist

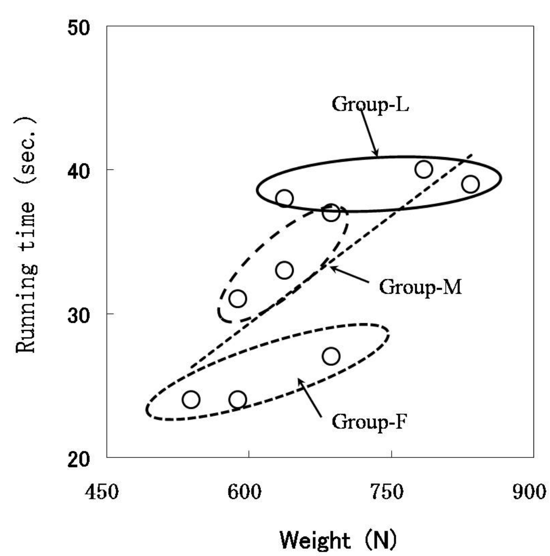


Fig.11. Relation between weight and manipulation ability

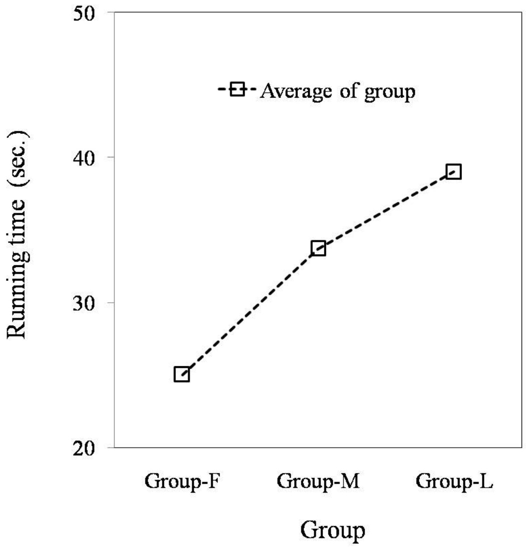
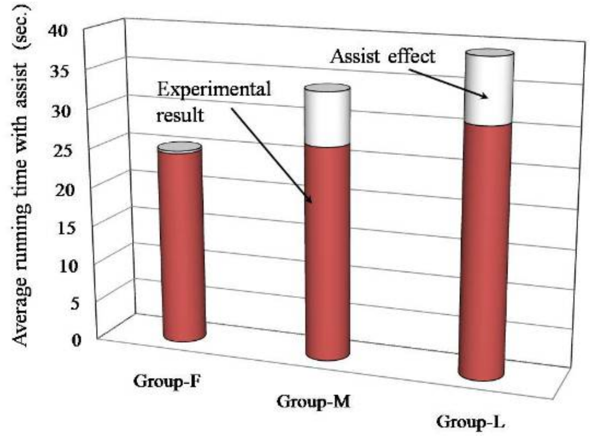


Fig.12. Average manipulation ability of each group



	Group-F	Group-M	Group-L
□ Reduced time by assist (sec.)	0.3	6.7	8
■ Average running time with assist (sec.)	24.7	27	31

Fig.13. Manipulation ability and power assist effect

effects are compared by the average running time of the group. Fig.12 shows "the average running time of each group", which indicates the manipulation ability and shows that examinees with light weight have high manipulation ability. Fig.13 shows the relation between manipulation ability and power assist effect. In Fig.13, whole poles show the average running time without power assist, namely, the manipulation ability and white poles show the assist effect, namely, the height of white poles is

the average running time without power assist
– the average running time with power assist.

As shown in Fig.13, the power assist is effective for examinees with low manipulation ability. Furthermore, in every group, the average running speed approach to about 1 [m/s] which is the average walking speed of human. These results show the effectiveness of the power assist.

VI. Conclusions

We developed a new type assist units which has a new ON/OFF mechanism, in order to assist surely. In this paper, we implemented the new assist unit to the developing prototype of the one hand drive wheelchair. The running experiments by using the one hand wheelchair, equipped with the new type assist units, were carried out. These experiments shows that, by using the developed new assist units, the assist torque could be surely provided to one hand drive wheelchairs and the comfortable running could be realized. Furthermore, by the running experiment of the one hand drive wheelchair, the assist effect according to the manipulation ability was verified. The reduction in size and weight of the assist unit is future problem.

References

[1] G. Bourhis, O. Horn, O. Habert and A. Pruski, "An autonomous vehicle for people with motor disabilities," *IEEE Robotics & Automation Magazine*, pp. 20-28, 2001.
[2] Y. Adachi, K. Goto, A. Khiat, Y. Matsumoto and T. Ogasawara, "Estimation of user's attention based on Gaze and environment measurements for robotic wheelchair," Proc. of the 12th International IEEE Workshopon Robot and Human Interactive Communication, pp.97-103, 2003.
[3] J. Urbano, K. Terashima, T. Miyoshi, H. Kitagawa, "Velocity control of an Omni-directional Wheelchair Considering User's Comfort by Suppresing Vibration," Proc. of 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.2385 – 2390, 2005.
[4] T. Yasuda, D. Furikado and K. Tanaka, "One hand drive wheelchair with new manipulation mechanism and assist functions," Proc. of 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.2833 – 2838, 2006.
[5] K. Sakai, T. Yasuda and K. Tanaka: Improvement of manipulation torque transfer mechanism and assist unit for one hand drive wheelchair with a triple ring, Proc. of the 2009 IEEE International Conference on Robotics and Biomimetics, pp.196-201, 2009.