Letter

Evaluation of Changes in Power Wheelchair Maneuver Induced by a Downhill Turning Prevention Control on Cross Sloped Surfaces

Jun Suzurikawa[*,**], Member
Takafumi Kinoshita[*], Non-member
Takenobu Inoue[*], Non-member
Mitsuhiro Kamo[***], Non-member
Norikazu Iida[***], Non-member
Kakuya Iwata[****], Non-member
Osamu Matsumoto[****], Non-member

In order to improve direction stability of a power wheelchair on a cross sloped surface, a downhill turning prevention control (DTPC) has been developed by some researchers and wheelchair suppliers. The DTPC-induced effect on wheelchair maneuver, however, has not been well clarified. In this study we quantitatively assessed DTPC-induced changes in joystick control strategies during a driving task on a cross sloped test course. Among several evaluation measures calculated from the joystick inputs during the test trials, the x-axis joystick displacement amount was found to be significantly decreased by the DTPC. This result suggests that the DTPC can save wheelchair users from the burden of compensation control on cross sloped surfaces.

Keywords : downhill turning tendency, cross slope, smart wheelchair, man-machine interaction, evaluation

1. Introduction

Downhill turning tendency of wheelchairs on cross sloped surfaces is one of main problems that hamper stable driving and thus threaten safety of the users [1]. This unintended veer results from the moment arm of the center of gravity about the downhill-side wheel, which affects the running direction of front casters. In order to overcome this unstable behavior of wheelchairs, safety systems with a downhill turning prevention control (DTPC) have been developed by some researchers and wheelchair suppliers [2],[3]. A standard DTPC system is designed to automatically detect and compensate for gravity- or terrain-induced behaviors of wheelchairs [2]-[4]. Power wheelchairs with DTPC are already commercially available like "G-Trac™" by Invacare®. To our knowledge, however, few researches have assessed the effect of the DTPC on wheelchair maneuver.

In this study, in order to obtain objective evidence of the DTPC's benefit we investigated how the DTPC influences wheelchair maneuver strategies during a driving task on a cross sloped surface. For objective and quantitative assessment, joystick control and wheelchair behavior were recorded during the task performances with and without the DTPC.

* Department of Assistive Technology, Research Institute of National Rehabilitation Center for Persons with Disabilities
4-1, Namiki, Tokorozawa, Saitama 359-8555, Japan
E-mail address: suzurikawa-jun@rehab.go.jp
** PRESTO, Japan Science and Technology Agency
4-1-8, Honcho, Kawaguchi, Saitama 332-0012, Japan
*** AISIN SEIKI Co., Ltd.
2-1, Asahi-machi, Kariya, Aichi 448-8650, Japan
**** Intelligent Systems Research Institute, National Institute of Advanced Industrial Science and Technology
Central 2, 1-1-1, Umezono, Tsukuba, Ibaraki 305-8568, Japan

2. Materials and Methods

Figure 1 shows a test course with an 8-degree cross slope and a test wheelchair. The test wheelchair was a rear-powered one that matched Japanese Industrial Standards (JIST9203, electric-motor-driven manual wheelchair) and was mounted with a custom-made DTPC system. The details of the DTPC were described in ref. 4. In short, the DTPC system employs proportional-integral (PI) control, which modulates angular velocities of drive wheels to offset a difference between an actual yaw rate measured by a rate gyro and a target yaw rate defined by the joystick input. Six subjects with physical disabilities (the weights ranging from 47 to 65 kg, the heights ranging from 153 to 170 cm) participated in the test drive. All the subjects had over one-year experience of daily use of a power wheelchair. The subjects were instructed to keep as straight as possible during a task, driving between the lines spaced at 4 m apart. Test trials were repeated fifteen times in each control status, i.e. with the DTPC being on/off. Both the subjects and an experiment instructor (occupational therapist) for ensuring safety were not informed of the on/off status during the task performance.

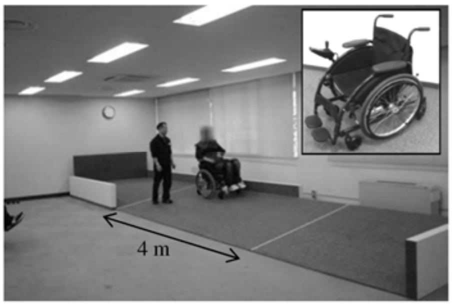

Fig. 1. Test course with an 8-degree cross slope. A test wheelchair with the DTPC is shown in the inset.

X-axis (left/right) and y-axis (forward/backward) joystick angular displacements, angular velocities of the drive wheels and video movies were recorded during the trials.

For quantitative analysis, seven evaluation measures were calculated from the acquired data and averaged for fifteen trials. The measures include a lateral displacement of the wheelchair after running through the test surface, time to complete each trial, x- and y-axis joystick displacement amounts ($JDA_{x,\ y}$), x- and y-axis joystick displacement variation amounts ($JDVA_{x,\ y}$) and a yaw rate amount (YRA). The lateral displacements of the wheelchair body were measured from the video recordings. The JDA and JDVA were calculated as follows:

$$JDA_x = \int_{T_{start}}^{T_{goal}} \left| JS_x(t) \right| dt \quad \cdots\cdots(1)$$

$$JDVA_x = \int_{T_{start}}^{T_{goal}} \left| \frac{d}{dt} JS_x(t) \right| dt \quad \cdots\cdots(2)$$

where $JS_x(t)$ is a time course of x-axis joystick angular input, and T_{start} and T_{goal} are times of starting and finishing each trial. The JDA is a temporal amount of an absolute joystick displacement from the neutral position during the driving task, whereas the JDVA is an amount of the input variation, which quantifies stability of the joystick input. The YRA also indicates stability of wheelchair behavior and was calculated by Eq. (1), $JS_x(t)$ of which was replaced with the yaw rate. The yaw rate was calculated from the angular velocities of drive wheels.

This experiment was approved by the institutional review board at National Rehabilitation Center for Persons with Disabilities and all subjects provided their informed consent.

3. Results and Discussion

Figure 2 shows time courses of x-axis joystick inputs (JS_x) and their differentials ($d(JS_x)/dt = JS_x$') during the driving tasks with the DTPC being on/off. As compared to the trial with the DTPC, the joystick displacement during the trial without the DTPC clearly included an offset component for compensation of gravity-induced downhill turning. The differential time courses of the x-axis inputs, on the other hand, showed no distinct difference in maneuver tendencies between the trials with and without the DTPC. In Table 1, the seven evaluation measures are summarized with means, standard deviations (SDs) and p values between the trials with and without the DTPC (two-sided t-test). Thanks to the DTPC, the mean JDA_x value, or temporal summation of $JS_x(t)$, dropped to one third of that without the DTPC. This means that the DTPC successfully replaced the manual directional compensation by the subjects. These observations clearly demonstrate the effectiveness of the DTPC on wheelchair maneuver. The distinct decrease of the JDA_x is likely to lead to reduction of the driving burden especially for persons with upper-body physical impairments [5].

The fact that the other evaluation measures than the JDA_x remained unchanged regardless of the DTPC being on/off will be attributable to superior driving skill of experienced wheelchair users. That is, the manual compensation of the gravity-induced veer by the subjects was sophisticated enough not to significantly affect the measures unrelated to the compensating operations. As Sorrent and his colleagues indicated [6], however, experiments with less experienced subjects and/or more challenging test courses than those in the present study might unveil DTPC-induced changes in the other measures. The number of subjects should also be increased for further detailed analyses.

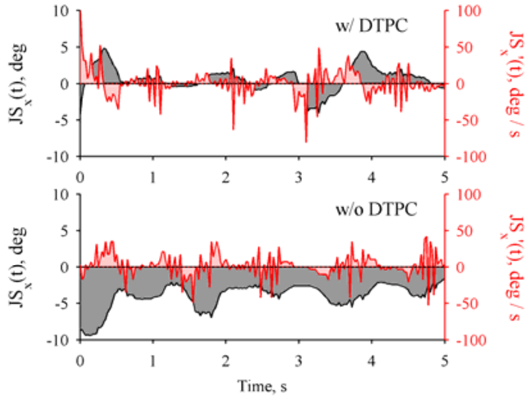

Fig. 2. Time courses of x-axis joystick angular displacements. Angular displacements (black, left axis) and the differentials (red, right axis) are shown for typical trials with (top panel) and without (bottom) the DTPC by the same subject. Joystick inputs for the downward direction of the cross slope (leftward to the travelling direction in Fig. 1) are defined as positive.

Table 1. Evaluation measures (N = 6).

Evaluation measure	With the DTPC		Without the DTPC		p value (t-test)
	Mean	SD	Mean	SD	
Displacement, cm	7.1	5.8	6.5	3.6	0.829
Time, s	6.9	1.8	7.1	1.2	0.910
JDA_x, deg s	9.85	3.30	29.3	8.33	3.45×10^{-4}
$JDVA_x$, deg	45.7	23.2	50.9	25.3	0.718
JDA_y, deg s	187	10.5	184	17.0	0.729
$JDVA_y$, deg	49.4	10.3	52.5	10.2	0.617
YRA, deg	0.377	0.113	0.394	0.067	0.747

4. Conclusion

In this study we have obtained quantitative evidence supporting the effectiveness of the DTPC on wheelchair maneuver. Comparison of joystick controls with the DTPC being on/off revealed that the DTPC significantly reduced a total amount of x-axis (left/right) joystick displacements during the driving task on a cross slope. This reduction of joystick displacement will be beneficial for persons with upper-body physical impairments.

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