Proposal of an Automobile Driving Interface Using Gesture Operation for Disabled People

Yoshitoshi Murata, Kazuhiro Yoshida
Faculty of Software and Information Science
Iwate Prefectural University
Takizawa, Japan
y-murata@iwate-pu.ac.jp, kyoshida@ipu-office.iwate-pu.ac.jp

Kazuhiro Suzuki, Daisuke Takahashi
JFP Inc.
Morioka, Japan
ss@jfp.co.jp, takahashi@jfp.co.jp

***Abstract*— A steering operation interface has been designed for disabled people that uses gesture operation. It incorporates both non-linear and semi-automatic steering control. Experiments using a gyro sensor and a driving simulator demonstrated that the driving operation is close to that achieved with conventional steering wheel operation. Sufficient practice in using the proposed interface should therefore enable a user to achieve steering control closer to that achieved with a steering wheel.**

Keywords-automobile driving interface; disabled people; gyro sensor; gesture operation; body part operation

I. INTRODUCTION

Disabled people generally want to stand on their own two feet, and achieving mobility is an important step in doing this. One way to enhance mobility is through the use of an automobile to which a driving-assistance device has been attached. However, there has been a lack of development of auxiliary devices and systems that would enable disabled people, especially people with arm and wrist disabilities, to drive a car. For example, the first such system, the original of Honda's Franz system [1], was developed in the 1960s. With this system, a car is operated with only the feet. Since the steering wheel is turned by pumping the pedals, its operation is not intuitive.

With the system developed by Wada and Kameda, the steering wheel is controlled with a joystick, and the brake and accelerator are controlled with another joystick [2][3]. This system has aided many disabled people, but strength is needed to operate the joysticks. Moreover, the levers onto which the joysticks are fixed have to be customized for the hand positions of each user.

In any case, mechanical devices such as these lack flexibility and have to be customized for the user. Hence, they are inherently expensive.

The on-going shift from hydraulic to electronic driving interface systems (steering, braking, etc.) means that systems combining computer chips with sensors can now be used to easily control these driving interfaces. Candidate sensors include the KINECT sensor, a gyro sensor and so on.

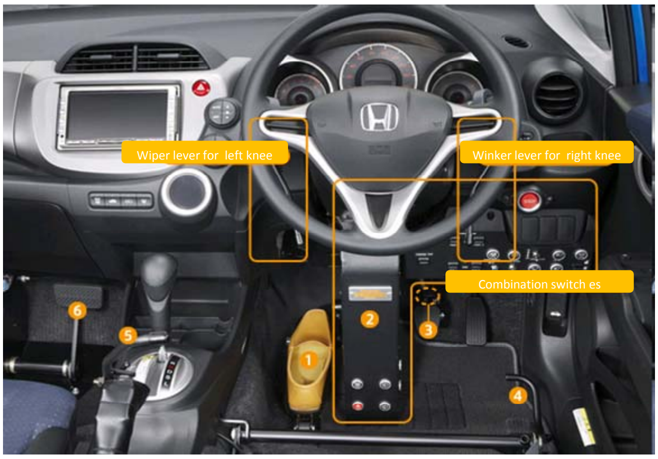
We have designed a steering operation interface for disabled people that is operated by gestures, developed a prototype control device that uses a gyro sensor, and evaluated it by using a driving simulator as the initial stage of our research.

After discussing related work in Section II, we describe the gestures, i.e., body-part movements assigned to the various functions in Section III, the driving simulator we developed to evaluate our proposed driving interface in Section IV, and the experimental evaluation we conducted in Section V. The key points are summarized and future work is mentioned in Section VI.

II. RELATED WORKS

A. Driving Interface for Disabled people

The Franz system used by Honda was aimed at people who have difficulty moving their arms and/or hands. The user operates a car using only his or her feet [1]. It was originally implemented in the Honda Civic in 1982, creating the first



(1) Steering pedal
(2) Steering box
(3) Brake lock button
(4) Selection bar for feet
(5) Side brake for knee
(6) Sub-brake for exercise

Figure 1. Honda's Franz system

Funding for this work was received from the Iwate Strategic Research Foundation.

 ISBN: 978-1-61208-250-9

vehicle for disabled people in Japan. It has now been implemented in the Honda Fit.

The steering wheel is turned right or left by pumping a steering pedal (see Fig. 1). The transmission is shifted into drive by lifting the selection bar, into reverse by pushing it down, and into park by pushing it further down. The turn signals and windshield wipers are operated by turning levers using the right and left knees. Power windows, lights, and so on are controlled by flipping switches up or down using the right foot or knee.

Wada and Kameda developed a joystick car driving interface for wheelchair users. In the initial version [2][3], the steering, braking, and acceleration were controlled with one joystick. In the latest version, two joysticks are used, as shown in Fig. 2. The right joystick controls the steering, and the left one controls the acceleration and braking. The relationship between the angle of the steering wheel and the angle of the joystick is a polyline, as shown in Fig. 3. This means that a driver can sensitively control the steering wheel around the neutral position and can turn the wheel quickly when making a wide turn. People who can freely move their hands can drive an automobile using this device.

In any case, such mechanical devices must be customized to fit the user's disability and physical form.

B. *Sensors for gesturing*

Several driving interfaces using the KINECT sensor have been developed. With the "Air Driving" interface developed by Forum8, a user can drive a virtual car in a simulated world by moving his or her hands and feet in front of the sensor [4]. Since there must be at least 50 cm between the sensor and the gesturing body part, it cannot be used in an actual car. Rahman et al. developed a car audio operation interface that uses a KINECT sensor [5]. Although this interface has been demonstrated in an actual car, its use as a driving interface (steering, braking, etc.) has not been examined.

Döring et al. developed a multi-touch steering wheel that can control not only the steering but also the car audio [6]. However, users with an arm disability have trouble operating it.

Other examples of using an acceleration sensor and/or a gyro sensor as a gesture operation interface include video games and home appliance remote controls [7].

III. GESTURES (BODY-PART MOVEMENTS) FOR OPERATION

A. *Operating functions*

Door open/close, window open/close, wiper on/off, and turn signal on/off functions are needed to drive an automobile in addition to the basic operations of steering, braking and accelerating. Moreover, since automobiles typically have an audio system, a navigation system, and a climate control system, a driver should be able to operate these systems as well. Other than for the basic operating functions, a fine degree of control is not needed for the operating functions—they can generally be controlled by flipping a switch, as in Honda's Franz system. Moreover, voice-command control systems like that used for Samsung's SMART TV [8] could also be used.

Of the basic operations requiring a fine degree of real-time control (steering, braking and accelerating), we focused on steering, which requires the finest degree of control. Our research results should be easily transferable to braking and accelerating.

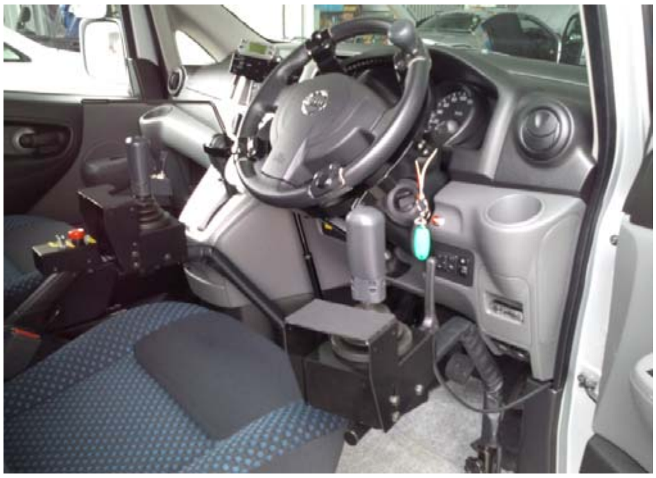


Figure 2. Wada and Kameda's joystick driving interface

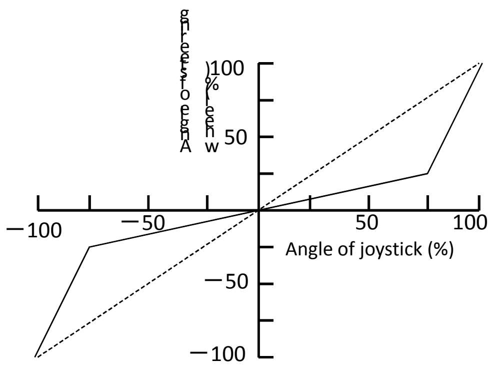


Figure 3. Relationship between angle of joystick and angle of steering wheel

B. *Steering operation requirements*

Steering an automobile by moving a body part should produce the same results as steering by turning the wheel by hand. Given this basic requirement, we derived several specific requirements.

1) *The automobile should be steerable within ± several ten degrees from the neutral position.*
   - *There should be a fine degree of steering control around the neutral position.*
   - *Steering should be quick when making a wide turn.*
2) *The driver should be able to keep the vehicle within the lane on both straightaways and curves of various radii at a normal driving speed.*

3) The driver should be able to drive stably, not zigzag, on straightaways

4) The driver should be able to traverse a curve while keeping the steering wheel at a position fixed immediately before entering the curve and then exit the curve into a straightaway by gradually returning the steering wheel to the neutral position.

C. Candidate sensors or devices

We considered four types of sensors or devices for controlling steering.

- KINECT sensor
- Video camera
- Rotary encoder
- Gyro sensor

Using a KINECT sensor or video camera is problematic because the unit has to be attached to the car, and the locations for possible attachment are limited. Moreover, as mentioned above, there must be at least 50 cm between a KINECT sensor and the gesturing body part, which greatly limits the possible attachment locations.

A rotary encoder requires the use of a mechanical adapter to measure the joint angle of a finger, an elbow, an ankle, and so on.

Since a gyro sensor is affected by not only the joint angle but also the vehicle motion, it must be attached to the vehicle to eliminate this effect. Moreover, a gyro sensor has a drift error that increases cumulatively. Since it is very difficult to remove the cumulative error completely, the measurement angle has to be reset using reliable data measured by another means.

A strain gauge does not have a drift error and is not affected by vehicle motion, so it should be better suited for measuring joint angles than a gyro sensor. We plan to investigate its usefulness in future work.

In this work, we investigated the use of a gyro sensor (ATR Promotion WAA-010) as well as a joint angle such as a finger, an elbow, or an ankle for driving a car.

D. Steering control

The steering wheel in an actual automobile can be turned about three complete revolutions from wheel lock to wheel lock (about 1080°). In contrast, the movable angle of a joint angle is about 20–90°, much less than that of a steering wheel. Hence, it is impossible to control the steering with a joint angle the same as is done with a steering wheel.

We thus introduce non-linear steering control and semi-automatic steering control. The direct operation angle and automatic steering angle are determined as shown in Fig. 4, which illustrates steering control using a foot and ankle. A driver operates the steering using the non-linear steering control within the direct operation angle. Whereas Wada and Kameda used a polyline function for their joystick steering control, we use a non-linear function ($y = x^n$). We set n = 3 on the basis of our experimental results, which are described in Section V. The steering angle increases automatically when it is beyond the direct operation angle. The rate of increase depends on the speed of the car: the faster the car, the lower the rate. The driver can stop a further increase in the steering angle by lifting his or her toes (about 20° for the case illustrated in Fig. 4). The driver can return the steering angle to the neutral position by lowering his or her toes. The drift error is canceled by performing this operation while the car is running straight.

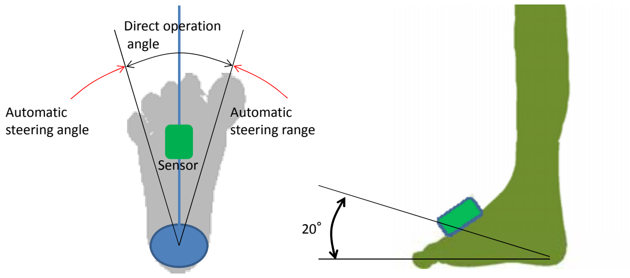


Figure 4. Example of controlling the steering by foot

E. Sensor attachment and actions

We measured the car control characteristics for several actions: rolling the ankle, moving the forefinger, moving the wrist, rolling the lower arm, moving the lower arm backward and forward, and moving the upper arm backward and forward. The position of the sensor and the motion of each body part are as follows.

[Rolling the ankle]

We considered using knee turning and knee movement for moving the gyro sensor. However, these movements produce a narrow movable angle, so we used rolling the ankle. The sensor is placed on top of the feet, as shown in Fig. 4. The sensor moves when the foot is pivoted right or left on the heel.

[Moving the forefinger]

The sensor is placed on the top portion of the top joint of the forefinger and is moved as shown in Fig. 5.

[Moving the wrist]

The sensor is placed on the back of the hand and is moved as shown in Fig. 6.

[Rolling the lower arm]

The sensor is placed on the lower arm and is rolled as shown in Fig. 7.

[Moving the lower arm backward and forward]

The sensor is placed on the back of the lower arm and is moved as shown in Fig. 7.

[Moving the upper arm backward and forward]

The sensor is placed on the upper arm and is moved as shown in Fig. 8.

 ISBN: 978-1-61208-250-9

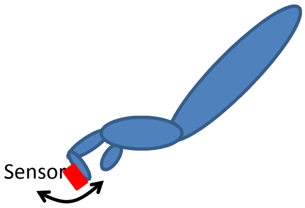


Figure 5. Moving the forefinger

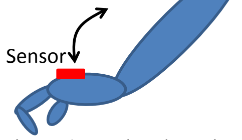


Figure 6. Moving the wrist

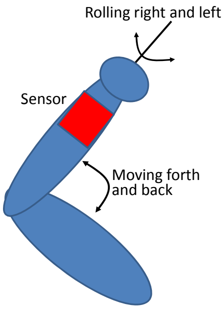


Figure 7. Rolling and moving the lower arm

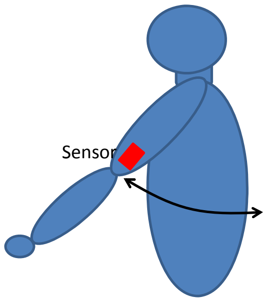


Figure 8. Moving the upper arm

IV. DRIVING SIMULATOR

We evaluated our driving interface by using a driving simulator. We used OpenGL [9] as the 3D program interface and developed the program using the "glut", "sdl" [10], "glew", and "OpenAL" tools [11]. The simulated car was operated by using a gyro sensor as the steering controller, the brake pedal, and the acceleration pedal.

A. *Driving course*

Our ultimate aim is to help disabled people obtain a driver's license, so we designed the driving course on the basis of a typical driving school course (Fig. 9). It comprised a rectangular outer course, two crank-shaped courses, two S-shaped courses, and two parallel parking courses. The outer course was 300 × 120 m and had a corner radius of 20 m. A 3.3-m-wide driving lane ran in each direction.

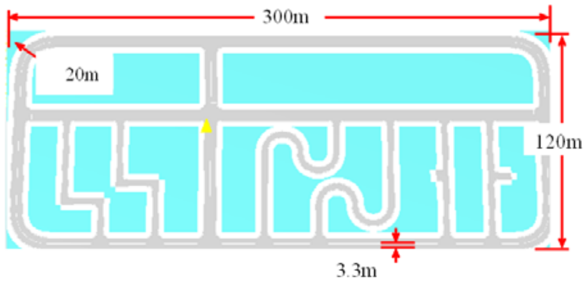


Figure 9. Driving course for simulation

B. *Motions*

Two motions were simulated: gyration and acceleration [13].

1) *Gyration*

A steady gyrating motion was applied to the car under the following assumptions.

- The movement of the car was the broadside motion of a rigid body. That is, the car was rigid and free of distortion.
- The speed was constant throughout each curve.
- The characteristics of the right-side tires were the same as those of the left-side tires.

The radius of the gyrating movement is given by the following equation in which V is the running speed and δ is the steering angle.

$$R = (1 + CV^2)\frac{1}{\delta} \tag{1}$$

The C is given by the following equation, in which the mass of the car is m, the cornering force on the front tires is K_f, that on the rear tires is K_r, the wheel base is l, and the distances between the car's center of gravity and the front and rear axles are l_f and l_r.

$$C = -\frac{m}{2l^2}\frac{l_f K_f - l_r K_r}{K_f K_r} \tag{2}$$

Each parameter was set to produce driving characteristics similar to those of an actual car. The cornering force was controlled by adjusting the radius of the gyrating movement: the larger the radius, the stronger the cornering force.

2) *Acceleration*

The acceleration A_c of an actual car depends on the engine torque, the transmission gear ratio, the tire radius, the vehicle weight, and the engine speed. The engine speed depends on the degree to which the accelerator pedal is pressed.

Air resistance R_a and rolling resistance R_r are considered to be the total running resistance.

$$R_a = \frac{1}{2}C_d \rho S V^2 \tag{3}$$

 ISBN: 978-1-61208-250-9

where C_d is the aerodynamic coefficient, ρ is the fluid density of the air, and S is the gross surface area of the car.

$$R_r = C_{rr} mg \tag{4}$$

where m is the mass of the car, C_{rr} is the rolling coefficient, and g is the gravitational acceleration. Resultant acceleration A is given by

$$A = A_c - (R_a + R_r) \tag{5}$$

C. Simulation display

An example view through the windshield is shown in Fig. 10. The upper right portion shows the position of the car on the course. The operation monitoring tool we developed to facilitate operation is shown in Fig. 11. It helps the driver recognize the angle of the sensor as the angle of the steering wheel and the angle of the toes. It also displays the degree to which the accelerator or brake pedal has been pushed.

Figure 10. Example view through front window

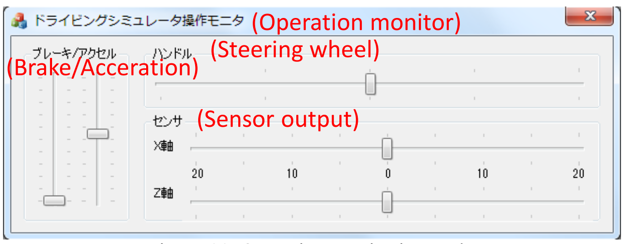


Figure 11. Operation monitoring tool

D. Measured data

Nine data items were measured.

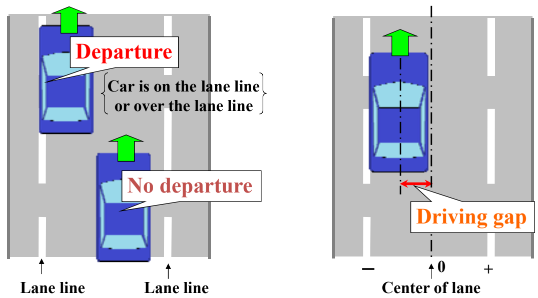
1) *Steering angle*
2) *Running speed*
3) *Distance driven and driving time*
4) *Position of car on course*
5) *Distance between left side of car and left-side lane marker line*
6) *Distance between right side of car and right-side lane marker line*
7) *Degree to which accelerator pedal was pushed*
8) *Depth to which brake pedal was pushed*
9) *Angle of car relative to driving direction*

V. Evaluation

A. Steering control

To analyze performance against the 2nd and 3rd steering operation requirements described in Section III-B, we calculated the ratio of lane departure (RLD) and the standard deviation of the driving gap (SDDG).

- As illustrated in Fig. 12(a), lane departure means that one or more of the tires run on or across a lane marker line. RLD is the ratio between the distance driven and the distance during which the car departed the lane.
- As illustrated in Fig. 12(b), the driving gap is the distance between the lane center and the car's center line. A value of zero means that the car is centered in the lane. SDDG was calculated using the values obtained for the car running on a straight portion of the course.



(a) Lane departure (b) Driving gap

Figure 12. Lane departure and driving gap

Since the first objective of this research is to develop a driving interface for arm and finger disabled people, we focused on foot-controlled steering, as illustrated in Fig. 4.

A non-linear function ($y = x^n$) was used to control the steering within the direct operation angle. We measured the position of car on course and calculated the RLD and SDDG for n=1 – 4 in $y = x^n$. We also measured and calculated the same data using a steering-wheel-type game controller for comparison. The measured and calculated data used for the non-linear function are listed in Table I for one of the four participants, a person with much experience driving a car using his foot with the proposed driving interface. Since the details of the experiment by Wada and Kameda were not published, we did not compare the performance of our control function with theirs.

We initially thought that a driver could easily operate the car by using semi-automatic steering control. However, the RLD and SDDG were much worse than with the game controller when the direct operation angle was ±15° and the corresponding steering wheel angle was ±30°. We observed that it was very difficult to drive the car using semi-automatic steering control during typical driving maneuvers. As illustrated in Fig. 13, neither of the two participants in this experiment negotiated the corners of the rectangular outer

 ISBN: 978-1-61208-250-9

course smoothly under those conditions. We concluded that semi-automatic steering control is suitable only for parking and traversing a crank-shaped course and that non-linear steering control is better for typical driving maneuvers. As shown in Table I, RLD and SDDG were the smallest for n = 1. But, the difference in values between n = 1 and n = 3 is negligible. RLD was the smallest for n = 3 during the latter laps, as shown in Fig. 14. This means that a driver tends to continue to drive longer when n = 3.

We measured and calculated the same data for three other participants (students) for $y = x^3$ (DOA=±20°, SWA±180°) for comparison with $y = x^1$ (DOA=±15°, SWA±30°) to see whether other drivers showed the same tendencies as participant Y. There were four participants in total, but not all of them participated in each experiment. The measured and calculated data are listed in Table II. The values for "Other" are the averages for the other participants.

TABLE I. MEASURED AND CALCULATED DATA FOR NON-LINEAR CONTROL FUNCTION

	y=x	y=x²	y=x³	y=x⁴	y=x	Game str. wheel
Operating body part	Left feet					
DOA*	±20°				±15°	
SWA**	±180°				±30°	
Distance driven (m)	791.3	790.9	790.9	790.9	795.4	790.0
Ave. speed (km/h)	26.6	26.3	25.5	27.3	14.3	30.4
RLD (%)	0.15	0.38	0.24	0.91	9.8	0
SDDG (m)	0.21	0.24	0.27	0.29	0.15	0.11

*DOA: Direct operation angle
**SWA: Corresponding steering wheel angle

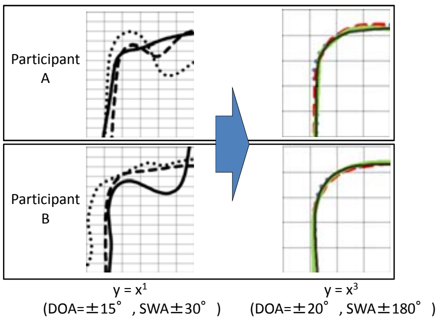


Figure 13. Cornering performance for participants A and B

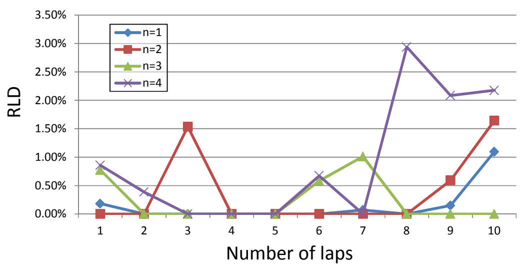


Figure 14. RLD against no. of laps

TABLE II. MEASURED AND CALCULATED DATA FOR MULTIPLE PARTICIPANTS

	y = x¹		y = x³		Game str. wheel	
Participant	Y	Other	Y	Other	Y	Other
Operating body part	Left foot				Hand	
DOA	±15°		±20°		—	
SWA	±30°		±180°		—	
Distance driven (m)	795.4	807.0	794.3	791.9	790.0	794.5
Ave. speed (km/h)	14.3	18.3	28.1	27.8	30.4	33.5
RLD (%)	9.8	52.3	3.3	12.5	0	2.3
SDDG (m)	0.15	1.31	0.35	0.46	0.11	0.21

Each participant's RLD and SDDG for $y = x^3$ (DOA=±20°, SWA±180°) was better than for $y = x^1$ (DOA=±15°, SWA±30°). Example cornering performances for two of the participants are shown in Fig. 13. Although every participant smoothly traversed the corners when $y = x^3$ (DOA=±20°, SWA±180°), none of them achieved driving operation comparable to that achieved with a steering wheel. However, it should be possible to eliminate the difference and achieve operation closer to that with a steering wheel through more practice and experience.

We calculated the RLD for the crank- and S-shaped courses for four participants as well. The measured and calculated data are listed in Table III. The values are the averages for them. Traversing the crank- and S-shaped course was more difficult than traversing the rectangular course. The driver had to use both non-linear and semi-automatic steering control. Driving performance for these two courses differed greatly. As shown in Figs. 15 and 16, the performance of participant D was very close to that with the game steering wheel while that of participant C substantially diverged from it. This indicates that performance with the proposed steering operation interface should approach that with a steering wheel as the amount of practice and experience increases.

TABLE III. MEASURED AND CALCULATED DATA FOR CRANK- AND S-SHAPED COURSE

	Crank-shaped course		S-shaped course	
Operation device	Game wheel	Sensor	Game wheel	Sensor
DOA	±20°			
SWA	±180°			
Cont. function	$y = n^3$ and semi-automatic steering control			
Distance driven (m)	79.9	78.2	123.6	125.8
Ave. speed (km/h)	9.7	8.3	15.0	12.9
RLD-Ave. (%)	17.2	22.9	8.9	16.8
RLD-Max. (%)	26.6	42.8	21.2	40.8
RLD-Min. (%)	6.6	8.5	0	1.2

 ISBN: 978-1-61208-250-9

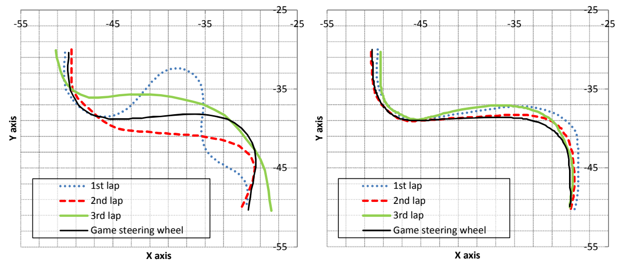


Figure 15. Crank-shaped course performance for participants C and D

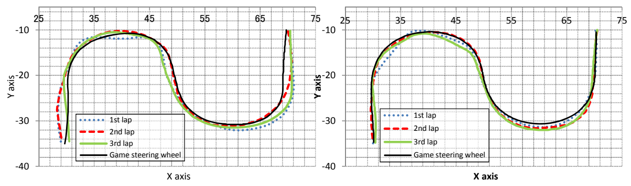


Figure 16. S-shaped course performance for participants C and D

B. *Results by body part*

To examine the applicability of the proposed driving interface to various types of disabilities, we measured and calculated the RLD and SDDG for steering control using the forefinger, the wrist, the lower arm, the upper arm, and the foot. The data measured for participant Y are listed in Table IV. The movements are illustrated in Figs. 5–8. The RLDs and the SDDGs for each body part were roughly the same except for the upper arm. The data for the upper arm was the worst because it is difficult to precisely move the upper arm (and shoulder). Although the forefinger had the largest DOA, its RLD was worse than that for the foot. The reason is that it is too easy to move the finger. An adapter might be useful in achieving steady forefinger movement.

TABLE IV. MEASURED AND CALCULATED DATA BY BODY PART

	Fore-finger	Wrist	Lower arm 1*	Lower arm 2*	Upper arm	Foot
DOA	±70°	±50°	±40°	±40°	±40°	±20°
SWA	±180°					
Cont. function	$y = n^3$					
Distance driven (m)	791.0	791.3	791.3	792.0	796.0	794.3
Ave. speed (km/h)	26.3	26.0	26.0	28.4	24.8	28.1
RLD (%)	3.8	3.2	4.7	4.2	17.6	3.3
SDDG (m)	0.35	0.26	0.26	0.26	0.33	0.35

*Lower arm 1: Moving lower arm forward and backward
*Lower arm 2: Rolling lower arm right and left.

VI. CONCLUSION

Our proposed steering operation interface for disabled people uses gesture operation. It incorporates both non-linear and semi-automatic steering control. Simulation experiments using foot control and a gyro sensor showed that semi-automatic steering control is suitable only for parking and traversing a crank- or s-shaped course and that non-linear steering control is better for typical driving maneuvers. The driving operation for each body part except for the upper arm was close to that achieved with a steering wheel. More practice in using the proposed interface should enable a user to achieve steering control closer to that with a steering wheel.

We plan to develop a prototype control device using a strain gauge instead of a gyro sensor and evaluate its driving operation for many participants. We also plan to evaluate our proposed interface in an actual car.

REFERENCES

[1] Development of Honda's Franz System Car; http://world.honda.com/history/challenge/1982franzsystemcar/index.html, January 2013.

[2] Joystick Driving System: allows wheelchair users to drive a car; http://www.itechdiary.com/joystick-driving-system-allows-wheelchair-users-to-drive-a-car.html, January 2013.

[3] Masayoshi Wada, Fujio Kameda, “A joystick car drive system with seating in a wheelchair”, IEEE IECON ’09, pp. 2163-2168, November 2009.

[4] FORUM8 Air Driving and RoboCar http://www.youtube.com/watch?v=LMr2dyfAzl0, January 2013.

[5] A.S.M. Mahfujur Rahman, Jamal Saboune, Abdulmotaleb El Saddik, “Motion-path based in car gesture control of the multimedia devices,” ACM DIVANet '11, Proceedings of the first ACM international symposium on Design and analysis of intelligent vehicular networks and applications, pp.69-75, November 2011.

[6] Tanja Döring, Dagmar Kern, Paul Marshall, Max Pfeiffer, Johannes Schöning, Volker Gruhn, Albrecht Schmidt, “Gestural interaction on the steering wheel: reducing the visual demand,” ACM CHI '11, Proceedings of the 2011 annual conference on Human factors in computing systems, pp.483-492, May 2011.

[7] Yoshitoshi Murata, Nobuyoshi Sato, Tsuyoshi Takayama, Shinetsu Onodera, “A Gesture-based Remote Control for Finger Disabled People”, IEEE, GCCE 2012, pp.411-415, October 2012.

[8] Samsung SMART-TV, http://www.samsung.com/us/2012-smart-tv/, January 2013.

[9] OpenGL – The Industry Standard for High Performance Graphics, http://www.opengl.org/, January 2013.

[10] Simple DirectMedia Layer, http://www.libsdl.org/, January 2013.

[11] Home – OpenAL, http://connect.creativelabs.com/openal/default.aspx, January 2013

[12] Masato Abe, “Automotive Vehicle Dynamics - Theory and Applications,” Tokyo Denki University Press, (2008).

[13] Giancalro Genta, “We apply the steady gyrating movement to a car under following assumptions,” World Scientific Publishing, 1997

 ISBN: 978-1-61208-250-9