Car-driving Interface with Load Cells for Upper-extremity-disabled People

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***Abstract*— Disabled people generally want to stand on their own two feet, and achieving mobility is an important step in satisfying that desire. A steering-operation unit for disabled people with disability in their arms was developed and experimentally evaluated. The unit consists of a set of load-cell sensors, one for turning right and one for turning left. The driver steps the right or left load cell to turn the car right or left. The magnitude of the driver's stepping force is converted to a voltage and input to the power-steering motor. The angular velocity of the steering wheel corresponds to that voltage. As a result of this configuration, the driver can drive a car just by moving their foot and intuitively selects the load-cell they must apply by foot to turn the car. Experimental results using a standard car fitted with the developed steering operation unit show that disabled people can drive the car with their foot in a manner close to that achieved with a steering wheel.**

Keywords-Car driving interface; disabled people; load cell; steering operation; foot operation.

I. INTRODUCTION

People who have physical disabilities generally want to stand on their own two feet, and achieving mobility on their own is an important step in satisfying that desire. One way for them to enhance mobility is by driving cars fitted with driving-assistance devices. However, only a few driving interfaces that enable disabled people, especially people with arm and wrist disabilities, to drive cars have been developed.

The first auxiliary device for people with arm and wrist disabilities, the original of Honda's Franz system [1], was developed in the 1960s. As for this system, the car is operated with the feet only. Since the steering wheel is turned by pumping the pedals, its operation is not intuitive.

The steering wheel in the system developed by Wada and Kameda in 2009 is controlled with a joystick, and the brake and accelerator are controlled with another joystick [2]. This system has aided many disabled people, but a certain amount of arm strength is needed to operate the joysticks. Moreover, the levers onto which the joysticks are fixed have to be customized to match the hand positions of individual users. In any case, mechanical devices, such as these lack flexibility and must be customized for individual users; hence, cars customized is this manner are inherently expensive.

At a glance, the autonomous car would be ideal solutions for disabled persons. In addition to those developed by Google, autonomous cars have been developed by many car manufacturers [3]. However, many disabled persons would like to not only reach a destination but also enjoy driving the car. Although several technologies, such as automatic braking and lane keeping, developed for autonomous vehicles would enable them to drive safely, riding in an autonomous vehicle would not satisfy their desire to drive.

A current realistic solution for disabled persons is to control steering with bodily appendages they can move. We have developed several kinds of steering-operation units until now. In case of the first operation unit we developed, namely, an angle sensor, the angle of the steering wheel changes according to the angle of a joint of the driver, such as the wrist or ankle [4]. As for the result of an experiment using the operation unit fitted in an experimental electric vehicle, the driver could drive the vehicle with the operation unit and achieved steering close to that with a steering wheel on gently curved roads. However, it was difficult for the driver to turn the car at intersections. To address that problem, we changed the angle sensor to a load-cell sensor [5].

We fitted the load-cell sensor in a standard car with a power-steering unit. A steering-control unit was designed for people with arm and wrist disabilities, and it was operated by the left foot. Since we noticed that it was difficult for a disabled driver to drive a car by forward and backward movement, not right and left movement, the steering-control unit consisted of a set of right and left load-cell sensors. The driver stepped on the right or left load cell to turn the car right or left. Results of an experiment using the developed steering-operation unit showed that the driver could drive the car with their left foot in a manner close to that achieved with a steering wheel on roads with not only gentle curves but also sharp bends.

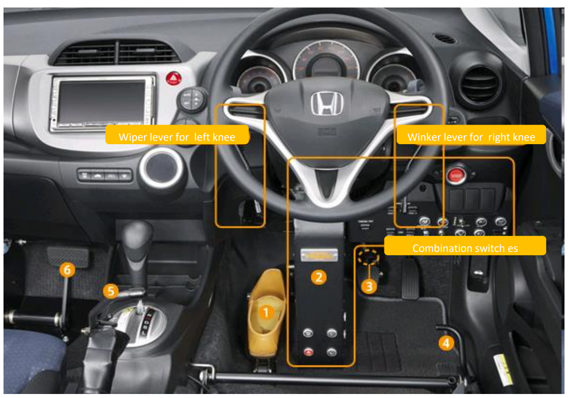
After introducing related works in Section II, actions by body parts suited for driving are explained in Section III, and results of our previous experiments using the angle-sensor operation unit fitted in an experimental vehicle are presented in Section IV. As for our latest study, described in Section V, we investigated whether the load-cell-sensor operation unit can be applied as a driving-interface unit. Section VI concludes this paper.

II. RELATED WORKS

Highly functional steering wheels have been developed by researchers in car manufactures or universities to easily drive a car for usual healthy people [6][7]. Sucu and Folmer challenged to develop a steering wheel for blind drivers [8]. Since the purpose of this study is to design an operation interface mainly for disabled people who has disabilities in the arm and/or wrist, we introduced existing advanced driving interfaces for people who have difficulty moving their arms and/or hands.

A. *Franz system*

The Franz system used by Honda is aimed at people who have difficulty moving their arms and hands [1]. The user operates a car fitted with the system with only their feet. It was originally implemented in a Honda Civic in 1982, which was the first vehicle to introduce the Franz system in Japan. It has now been implemented in a Honda Fit. The steering wheel is turned right or left by pumping a steering pedal (see Figure 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 with the right and left knees. Power windows and lights are controlled by flipping switches up or down with the right foot or knee.



(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

B. *Joystick operation*

Several kinds of the joystick-operation unit are available. Such a unit is usually adopted for people who do not have enough strength to control a steering wheel, an accelerator pedal, or a brake pedal because of a disability, such as a spinal-cord injury. They use joysticks instead of a steering wheel and pedals. The operation unit showed in Figure 2 was developed by Wada and Kameda [2]. It is available as two types. One is a single stick, by which steering, braking, and acceleration are controlled with one joystick. The other is a double stick, by which the joystick on the right controls the steering and that on the left controls acceleration and braking. The double-stick type is shown in Figure 2.

The relationship between the angle of the steering wheel and the angle of the joystick is a polyline, as shown in Figure 3. It means that the driver can sensitively control the steering wheel around a neutral position and turn the wheel quickly when making a wide turn. People who can freely move their hands can drive cars with this device. However, such mechanical devices must be customized to fit individual users' disabilities and physical form.

Figure 2. Wada and Kameda's joystick driving interface

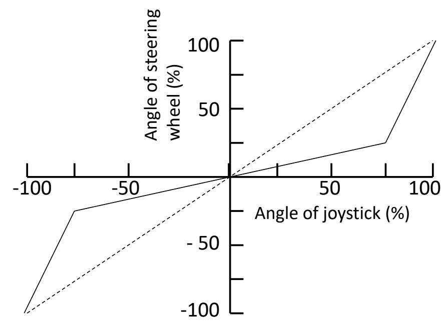


Figure 3. Relationship between angle of joystick and angle of steering wheel

III. DRIVING ACTION BY BODY PARTS

The purpose of this study is to design an operation interface for disabled people that is operated by body parts moving smoothly instead of by hand. In a previous study, therefore, we measured 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 [9]. The results obtained from the questionnaires (answered by 29 participants) are summarized in Table I. Most people chose the same action, such as rolling the lower arm, for motions that led to right or left movement of the car. For example, someone may move their finger down to turn a car to the right, while another may move their finger up to turn to the right. Hence, we obtained information about different motions by individuals by administering questionnaires before measuring the car-control characteristics.

However, the number of people who chose alternative actions, such as moving their fingers up or down, was roughly the same for actions that did not lead to right or left movement of the car. For example, 86% of people chose rolling their right lower arm to the right to turn the car to the right. However, 52% of participants chose "up" and 48% of them chose "down" for moving their left finger up or down.

The results listed in Table 1 show that the operation unit must be operated by the actions that lead to right and left movement of the car.

TABLE I. RESULTS FROM QUESTIONNAIRES ABOUT ACTIONS FOR TURNING THE CAR TO THE RIGHT

Left hand		Turn to right	Right hand		Turn to right
Finger	Up	15	Finger	Up	18
	Down	14		Down	11
Finger	Right	26	Finger	Forward (Right)	27
	Forward (Left)	3		Left	2
Wrist	Up	16	Wrist	Up	16
	Down	13		Down	13
Wrist	Right	24	Wrist	Right	27
	Left	5		Left	2
Lower arm	Forward	11	Lower arm	Forward	21
	Backward	18		Backward	8
Lower arm	Right	25	Lower arm	Right	28
	Left	4		Left	1
Upper arm	Forward	17	Upper arm	Forward	14
	Backward	12		Backward	15

IV. OPERATION UNIT USING ANGLE SENSOR

An operation unit using an angle sensor was developed and fitted in an electric vehicle. Three angle sensors were evaluated: a chromium-nickel sensor developed by the Research Institute for Electromagnetic Materials [10] and TMI-160 developed by Toyo Sokki Co., Ltd [11]. According to the results of the evaluation, TMI-160 was selected and attached to the parts of a subject's body, as shown in Figure 4. In this experiment, an experimental electric vehicle, PIUS [12], developed by MODI Co., Ltd., showed in Figure 5, was used. The driver shown in this figure has a disability due to taking the drug Thalidomide. Her arms are too short to operate a steering wheel. Nevertheless, she can operate a stick steering control system mounted on the vehicle chassis with her fingers. Servo motors were attached to the steering wheel, accelerator pedal, and brake pedal so they could be controlled by the sensor operation unit.

The drivability of the driving operation unit using the angle sensor was experimentally evaluated. The test courses used in the evaluation are a straight course, a square course, and a circuit course (see Figure 6). The drivability in terms of "straightness" and "turnability" were evaluated with the straight course and square course.

Figure 4. Mounting situation of angle sensor TMI-160

Figure 5. Experimental electric vehicle PIUS

Overall performance of the driving operation unit was evaluated with the circuit course.

In each test, the length between the right front tire and the center line on the straight and circuit courses was measured. Its average and Standard Deviation (SD) are listed in Table II. The standard deviation was assumed to shows the fluctuation. The number of participants in the tests was five. Sensors were attached to the middle finger, wrist, and ankle of the participants.

We measured the same data by the steering wheel operation to compare with them by the angle sensor unit. As introduced in Section III, it is difficult for a driver to imagine turning the car to the right or left from the up-down action of the thumb. Therefore, we suggested to the participants to turn their thumb upward. The action of the thumb and ankle control the right or left motion of the car in this position. In the case of driving by moving the ankle, we suggested to the subjects to tilt their knee outwards to easily image the right or left movement of their ankle. The SD of the measurements taken by the angle-sensor operation unit was greater than that of those taken by steering wheel. However, the difference in SDs was not significant.

TABLE II. DRIVING CHARACTERISTICS IN THE CASE OF DRIVING ON THE STRAIGHT AND CIRCULAR COURSES USING THE ANGLE-SENSOR OPERATION UNIT

Course	Operation	Running time [m.:s.]	Average [cm]	SD [cm]
Straight	Middle -finger	0: 58	53.3	6.6
	Wrist	1: 03	56.2	7.0
	Ankle	1: 04	55.8	6.2*
	S. wheel	0.59	54.0	6.1
Circuit	Middle -finger	6: 12	56.3	8.2
	Wrist	6: 22	56.5	10.0
	Ankle	7: 03	53.3	9.4
	S. wheel	6: 17	55.3	7.0

* One participant drove out of course; therefore, their data was discarded.

TABLE III. EVALUATION EXPERIMENTS USING A SUBJECT WITH DISABILITY

Device / BP	Running time	Length from center line	
	[m.:s.]	Average [cm]	SD [cm]
Stick operation unit	8:37	61.3	8.7
Ankle	8:22	59.0	5.8

*BP: Body parts

TABLE IV. THE NUMBER OF TIMES THE DRIVER DROVE OUT OF COURSE AT THE CORNERS

	Device/BP	Clockwise				Counter clockwise			
		A	B	C	Av	A	B	C	Av
The number of course out	SW	0	0	0	0	2	1	1	1
	Mid-finger	7	4	6	6	8	3	4	5
	Wrist	9	7	5	7	9	6	3	6
	Ankle	12	9	10	10	11	8	9	9
Rate of course out	SW	0	0	0	0	17	8	8	11
	Mid-finger	58	33	50	47	67	25	33	42
	Wrist	75	58	42	58	75	50	25	50
	Ankle	100	75	83	86	92	67	75	78

*BP: Body parts, A/B/C: Participants

A research partner, Ms. Masuyama was requested to evaluate the driving operation unit. She usually drives a car fitted with the Frantz system. She operated a stick operation unit by her fingers showed in Figure 5, and a sensor attached to her ankle. She drove the car fitted in this manner on the circuit course. The results of the measurements taken by the angle sensor are listed in Table III and plotted in Figure 7. According to these results, she could drive the car very well. Especially, her fluctuation characteristics were better than those in the case of using the steering wheel.

Drivability in terms of turning was also evaluated by using the square course (Figure 8). Three participants drove three laps on the square course in both the clockwise and counter-clockwise directions. The driver turned twelve corners in each direction. In this experiment, the number of times the driver drove out of course at the corners was recorded. The results of the experiment are listed in Table 4. According to these results, unfortunately, every participant could not turn the corners well by using the angle-sensor operation unit.

Figure 6. Test courses

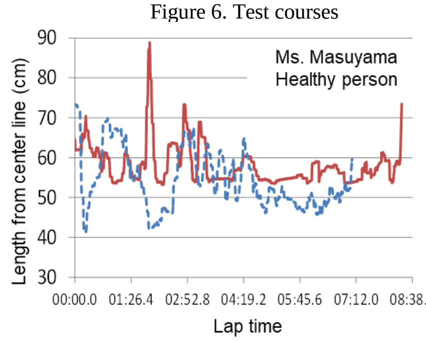


Figure 7. Distance from center line

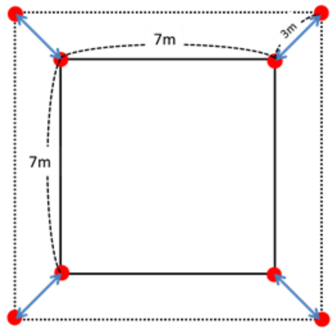


Figure 8. Square course for right and left turn

V. OPERATION UNIT USING LOAD CELL SENSOR

Participants could smoothly drive the car with the angle-sensor operation unit on the circuit and straight course, but they could not drive so well on the square course. Lock-to-lock angle of the steering wheel is about 800 degrees. On the other hand, the maximum range of movement of their body parts is roughly 90 degrees. That means it is very difficult for the angle-sensor operation unit attached to the body part to correspond to the lock-to-lock angle of the steering wheel. In consideration of that fact, the angle sensor was replaced with a load cell sensor. First, whether a load cell sensor operation unit can control the car with the hand in the same manner as the load cell operation unit was experimentally examined. According to the results of that experiment, the driver could drive the car by applying enough force. Based on that result, a load cell operation unit operated by foot was developed.

The load cell sensor operation unit is available for use as a driving operation unit. Hence, we designed a driving operation unit for people with arm and wrist disabilities. Since this operation unit comprised right and left load cells (see Figure 9), the driver can intuitively select a load cell and step on it to turn the car to the right or left. In this experiment, a load cell, Pedal Force Sensor (PFS) developed by Toyo Sokki co. ltd [5] was selected because it is easy to step on. The operation unit was connected to the power-steering motor of a standard car (namely, a Nissan Micra) as the test car. The operation unit was mounted on the car as shown in Figure 10. In the case of the power-steering motor, the steering rotation speed is changed according to an impressed voltage. Therefore, intensity of force applied to the load cell corresponds to the rotation speed of steering wheel (not to the angle of rotation of the steering wheel). Two control schemes were examined to determine the relationship between intensity of force applied to the load cell and control power supplied to the steering unit. Each control scheme is listed as follows:

“Digitize” scheme

(1) No intensity: the steering wheel is free. It returns to the neutral position by the force from the tires.
(2) Very weak: a foot is just put on the load cell, no stepping; the steering wheel stops at its position.
(3) Weakly stepping on: the steering wheel rotates slowly.
(4) Strongly stepping on: the steering wheel rotates quickly.

“Continuous” scheme

(1) Same as digitize scheme (1).
(2) Same as digitize scheme (2)
(3) Stepping on: rotation speed of the steering wheel changes according to intensity of the stepping force.

Drivability of the car fitted with the driving operation unit using the load-cell sensor operated by foot was experimentally evaluated. The results are shown in Table V. The test courses used in the evaluation were the straight course and circuit course (described in Section IV). Measurement data were also the same as that presented in Sections IV and V. The number of participants was seven. The driving characteristics are a little worse than those of the car operated by the angle-sensor operation unit and load-cell-sensor operation unit for the hand.

After that, turning drivability was evaluated. Since drivability of the car driven by the load cell sensor operation unit for the foot is superior to that in the case of the angle-sensor operation unit, the right/left-angle corner was used, and a white line was painted on the course to indicate traffic lanes, as shown in Figure 11. Each of the five participants in the test drove the car three times by using the load cell operation unit for the foot in each direction. For the sake of comparison, they also drove the car with the steering wheel. In this experiment, the number of drivers went out of the traffic lane was counted. According to the results of the experiment, every participant did not drive out of traffic lane in both the steering wheel and load cell operation unit for foot.

Since the drivers could drive the car well with a combination the digitized scheme and the power-steering unit, it was concluded that the drivers can also drive a standard car fitted with an operation device that has a neutral step and three steps each for right and left turning, totally seven steps. As such a device, an angle or load-cell sensor are usable, but not necessary.

TABLE V. DRIVING CHARACTERISTICS IN CASE OF STRAIGHT AND CIRCULAR COURSES BY OPERATING THE LOAD-CELL-SENSOR OPERATION UNIT BY FOOT

Corse	Operation Method	Length from center line SD [cm]
Straight	S. wheel	3.7
	Digitize	5.0
	Continuous	6.2
Circuit	S. wheel	8.7
	Digitize	10.2
	Continuous	10.6

We think the angle sensor or rotary encoder is one of best devices to be controlled by body parts (as mentioned in Section IV). Until now, it is expensive for disabled people to customize their car. However, they could drive their car if the sensor operation unit was simply connected to its power-steering motor. This operation unit is very flexible and cheap, and their car does not need to be significantly customized.

Figure 9. Operation of load-cell-sensor unit

Figure 10. Operation unit mounted in a car

Figure 11. Right/Left-angle corner used for evaluating turning drivability

VI. Conclusion

Several kinds of driving operation units for disabled people have been developed. With one of those units, an angle-sensor operation unit, the driver could drive well on roads with gentle curve. However, this sensor unit was found to be unsuitable for sharp corners. Accordingly, the angle sensor was replaced with a load-cell sensor. It was experimentally shown that the driver can control the angle of the steering wheel by adjusting the intensity of the stepping force they apply to the load cell. By connecting the load-cell operation unit to the power-steering unit on a standard car, it was experimentally shown that the driver can control the rotation speed of the steering wheel by adjusting the intensity of force applied to the unit. A driver could drive the car in a manner close to that achieved with a steering wheel after just a bit more practice than needed for a steering wheel. Moreover, it was found that a device that has seven steps, for example, an angle-sensor operation unit with seven steps, is suitable for enabling physically disabled people to drive a car. Since such a unit is very flexible, cheap, and needs little customization to fit in a car, it would be suitable for physically disabled people.

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