The Remote Controllable Electric Wheelchair System combined Human and Machine Intelligence for Caregivers and Care Receivers

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Chapter 1

Introduction

Recently, research and development work has examined practical applications of automotive driving technology. Automotive driving requires recognition of the environment, judgment of the situation, and operations planning by a machine instead of a human driver. Therefore, advanced information processing technologies such as artificial intelligence (AI) and sensor fusion are required. Technology in automatic driving can also be applied to machines other than cars, such as factory machines and personal mobility. However, with current technology it is still difficult to fully automate the drive function for personal mobility machines; hence, they have not been put to practical use on public roads.

Wheelchairs are important modes of mobility for older adults and for physically handicapped persons with limited movement. Electric wheelchairs began appearing on the market in the 1950s. Since then, people who have difficulty driving non-electric wheelchairs, due to lack of physical strength can easily drive electric wheelchairs. In nursing care facilities, it is necessary for the caregiver to remain beside the electric wheelchair at all times. The global population aged 60 years or over numbered 962 million in 2017. The number of older persons is expected to double again by 2050, when it is projected to reach nearly 2.1 billion [1]. In these aging societies, there are increasingly urgent demands for wheelchairs and caregivers. In addition, because of a shortage of caregivers, the burden on them is also increasing. How to reduce the burden on caregivers is a challenging problem.

To reduce this burden, a fully-automated electric wheelchair is ideal for caregivers who use wheelchairs in their work. The fully automatic wheelchair is a sterling solution to eliminate the burden on caregivers accompanying user. If driving and recognition of the environment is carried out automatically, the caregiver need not constantly supervise the

Table 1.1: Overview of experiments

	Number of participants	Target	Purpose
St1	12	Non-caregivers	To investigate the operability of the remote operation.
St2-Problem finding phase	6	Caregivers	To find the problems and solutions in care.
St2-Problem solving phase	2	Caregivers	To evaluate methods found during the problem finding phase.
St3	2	Care recipients	Verbal survey of older adult people who experience the intelligent wheelchair.

wheelchair user. Furthermore, the psychological burden faced by person riding a wheelchair is reduced if the wheelchair is operated by a machine without a caregiver's help. However, fully automatic operation is difficult, even while using technologies such as modern environmental sensors and AI. Therefore, as a preliminary step, this research proposed developing an electric wheelchair combining human operation with automatic operation using AI. AI performs object recognition and environment recognition, and helps humans manipulates basic wheelchairs. In addition, the wheelchair is operable from a remote location. This eliminates the need for a caregiver to physically move a heavy wheelchair, thus further reducing the burden on the caregiver.

This research developed an intelligent electric wheelchair called the Telewheelchair. This study conducted a user study 1 (Table 1.1) on the operation of the wheelchair in four modes (normal mode, standby mode, display mode, and HMD mode) and investigated the achievement time of the task.

To identify the functions to be installed in an intelligent electric wheelchair, this study explored the types of problems encountered in a practical nursing care environment. This research conducted two-part studies (Table 1.1) at a nursing home using the intelligent wheelchair. The study 2 aimed to find the problems and their solutions in the nursing care facility. Based on the results of that study, this research implemented the cooperative operation function with the intelligent wheelchair and demonstrated it at the nursing home (study 2-ploblem solving phase). The study 3 was a verbal survey of older adults who experienced the intelligent wheelchair.

Contributions of this research are as follows.

- This research conducted experiments on the operability of the wheelchair using an HMD and found that there was no significant difference between operability in a straight line and a right-angle curve.
- This research held a workshop at a nursing home, and from the feedback of the experiments, this research found that there was a problem of the workload of caregivers in nursing care.
- This research proposed a cooperative operation. Based on the implementation and feedback from the experiments, this research concluded it was a useful method to solve the problems in nursing care.
- This research demonstrated the usability of the remote control for the older adults, and found that they have are positive opinions of the intelligent wheelchair.

Chapter 2

Related Work

2.1 Automatic Operation of the Electric Wheelchair

Since the 1990s, many researchers have been studying the automatic operation of electric wheelchairs. Gundersen et al. [2] presented an electric wheelchair equipped with a remote-control system via an HMD and an obstacle detection system with an ultrasonic sensor. Their system is very similar to the Telewheelchair and can be considered a basic system in the automatic operation of a wheelchair. This research retrofitted their system using low-cost and simpler components by using general-purpose products and technology. Pires et al. [3] explored the usability of wheelchairs by conducting experiments on their operation using voice and joystick, and on obstacle detection and collision detection. The NavChair [4] has enhanced navigational functionality enabling guided door passage and wall following in addition to obstacle avoidance. Mazo [5] examined automatic driving by using various methods for environmental recognition and user's motion detection.

Some research focuses not only on designing a general-purpose electric wheelchair but also on automatic operation of specific motions. DECoReS [6] can be driven using orders as "go straight, fast" and "make a wide curve to the right". DECoReS can turn corners according to the user's preference. Kobayashi et al. [7] uses laser range sensors to move the electric wheelchair while keeping a certain distance from the accompanying carer. Passengers can communicate with their companions.

Many studies on automatic driving of wheelchairs have been conducted, but there is no fully automatic electric wheelchair that drive can without a human driver. Safety is important for older adults and people with disabilities. With current automatic driving technology, it is difficult to fully automate the wheelchair from the viewpoint of safety. Therefore, this research developed a semi-automatic electric wheelchair combining human operation and automatic driving.

2.2 Operation System of the Electric Wheelchair

Many discussions on how to operate electric wheelchairs have been conducted. The focus of these discussions is how care recipients who cannot move their hands because of being bedridden or paralyzed can handle a wheelchair. Popular methods involve operating wheelchair using electrooculography (EOG) and voice. Barea et al. [8, 9, 10] identified the EOG using a neural network and operated an electric wheelchair. By corresponding to the direction of the line of sight, it is possible to identify whether the wheelchair is moving or stationary. Wastlund et al. [11] installed an obstacle detection function in addition to the EOG operation system. Mazo et al. [12] is a pioneer in the field of wheelchair operation using voice command. They developed a method to transition the state of the wheelchair via voice commands and perform various operations. Nishimori et al. [13] discriminated the voice command with a discrimination rate of 98% and operated an electric wheelchair. AI-Rousan et al. [14] used a neural network for voice recognition.

Various other methods are also used as operation systems for electric wheelchairs. An electric wheelchair developed by Deligiannidis et al. [15] can be operated using hand gestures. Guedira et al. [16] developed an electric wheelchair with a touch input device or tablet for operation input, for users who cannot use a joystick. Besides EOG, there is an electric wheelchair with electromyography (EMG) as input [17] and an electric wheelchair with electroencephalogram (EEG) as input [18]. ExtendedHand [19] is a system that allows a person riding in a wheelchair to manipulate neighboring items using virtual extended hands. Shiomi et al. [20] compares the comfort of an electric wheelchair with an ordinary wheelchair to identify whether the elderly prefer a machine-operated wheelchair.

There are few operation systems for electric wheelchairs using VR. However, research on operation system for other vehicles exists. Flying head [21] operated by synchronizing the position of the human head and the action of the unmanned aerial vehicle. An unmanned aerial vehicle works in accordance with a human's movements such as walking, looking, and crouching. Forster et al. [22] developed stereoscopic 3D visualization in a fully immersive driving simulator and compared it with the driving simulator using the display. Weidner at el. [23] performed the Lane Change Task in a VR driving simulator and non-VR driving simulator and evaluated the performance in both system. They showed that VR and 3D driving simulators have significant advantages over conventional simulators.

2.3 Technical Approach for an Aging Society

In an aging society, psychological and physical burdens are placed on the older adults and caregivers. Many technological implementations are under way to reduce the burden on these groups. The portal monitor [24] is a monitoring system that addresses the privacy of older adults. Safety and consideration of the psychological problems of older adults have been studied. Ichinotani et al. [25] developed a deformable wheelchair and a nursing care bed. The systems are used to solve the problem of older adults getting hurt when transferring from a bed to a wheelchair. Huang et al. [26] conducted an approach to solve the loneliness and anxiety of the older adult through talking with CG animation agents. This method showed that active listening could be done at the same level as human beings. Conte et al. [27] proposed a system that provided tactile assistance for a tablet according to the learning preferences of older adults.

In addition, research has been conducted to investigate the relationship between technology and the aging society. Senior Care for Aging in Place [28] investigated how older adults live with both self-care and collateral care at the same time. This research found that many older adults need a monitoring system that does not violate their privacy. Technological Caregiving [29] conducted an interview survey on the caregiver side and the nursing care side about online support for older adults. This research showed that online nursing care activities are generally stressful to caregivers. Buccoliero et al. [30] aimed to clarify the factors that affect the adoption of technology concerning the health of older adults. Kostoska et al. [31] aimed to replace manual data collection with automatic data collection using a distributed system based on mobile phones and biosensors. Researchers [32] examined the specifications of PictureFrame, a new social technology to support the provision of medical examinations for older adults residing at home. Virtual Carer [33], a web service model, generated personalized recommendations for informal caregivers according to the need of older adults. Chen et al. [34] conducted an interview study on caregivers. Caregivers maintained the balance of their personal lives with work, family, and their caregiver roles with the concept of giving-impact and visibility-invisibility. Holbo et al. [35] examined factors to allow people with dementia to walk safely from workshops and interview.

Many technologies for the aging society were implemented as described above, and the relationship between older adults, caregivers, and technical approaches has been investigated from various perspective. However, there is little practical discussion of how technologies like automatic wheelchairs are perceived by older adult participants in nursing homes. This research tried the approach of simulating the automatic driving concept in practical experiments to discover methods to reduce the burden on older adult people and caregivers.

Chapter 3

Design

As I described in chapter 1, the fully automatic wheelchair is the ideal solution to eliminate the burden on the caregiver who uses the wheelchair. However, fully automatic operation is difficult with current technology. This research designed three scenarios based on the results of discussions with nursing caregivers.

3.1 Scenario A

In scenario A the wheelchair is fully automatically operated. Replacing all wheelchair movements with the automatic operation is the best way to reduce the burden on caregivers. The carergivers does not need to push the wheelchair. Furthermore, conventionally each wheelchair needed a single dedicated caregiver. However, if a wheelchair could be operated automatically, one caregiver may manage multiple wheelchairs. In addition, care recipients can navigate to their favorite places without relying on their caregivers. This leads to a reduction in the psychological burden of the care recipient. Thus, in this scenario, older adults and people with disabilities can act with greater autonomy.

However, there are some challenges. The first issue is safety. With current technology, it is difficult to fully recognize the environment and situation of the passenger. Therefore, unexpected accidents and passenger injuries may occur. Also, in terms of cost, it is difficult to install fully automatic operation systems in general electric wheelchairs.

3.2 Scenario B

In order to solve the problems encountered in scenario A, I considered that not all functionality needs to be covered by automatic driving; only certain specific functions could be automatically driven. In scenario B, only some functions are automatically operated. As a preliminary step of fully automatic operation, I considered developing an electric wheelchair combining human operation and automatic driving. The proposed system, performs object recognition and environment recognition using AI, to support human operation. Telewheelchair is not fully automatic, so in dangerous situations, it can be controlled by human operator. Also, by allowing a caregiver to operate from a remote location, the caregiver does not need to physically move the heavy wheelchair. This method wheelchair reduces the burden on caregivers. The remote caregiver wears an HMD and operates the wheelchair with the controller while watching the omnidirectional image from the viewpoint of the wheelchair. As remote control and obstacle detection are performed using images captured by a general-purpose omnidirectional camera, cost is similar to that of existing electric wheelchairs. As automatic driving technology develops, the weight of manual operation decreases, the percentage of automatic operation by AI increases, and it approaches scenario A.

3.3 Scenario C

Scenario C is a scenario focusing on better operability in order to make it easy to use the wheelchair in the field of nursing. I demonstrated an electric wheelchair developed based on scenario B to professionals in a nursing facility, and recorded their feedback. In nursing workspaces, most staff members were unfamiliar with the operation of the electric wheelchair and the operation of the joystick. Therefore, many insightful opinions were given on the operation system. Many professionals (nursing facility staff, 90% of whom were women) answered that the joystick is difficult to operate with respect to the operating system. This is considered to be due to a large deviation from the driver's consciousness, such as a time lag until the wheelchair starts to move against factors such as the stroke or reaction force, acceleration feeling, and straightness. These should be regarded as important issues in other operation systems for other such vehicles. In addition, most people were using HMD for the first time and they felt a strong feeling of strangeness when viewing the camera's viewpoint. Several people opined that they were more accustomed to controlling by arranging displays like a control room. The subjects pointed out that the perception of the operation is weak as the user's hand is not displayed at all in the image of the HMD. For staff who worked at a nursing care workplace, I considered that it is necessary to examine the operation system so that it is easy to operate, even with a controller and HMD that are unfamiliar objects for carers to use. Therefore, in order to achieve scenario C which emphasizes operability, in this study, I performed an experiment comparing the ease of operation of the four operation methods.

Chapter 4

Implementation

Figure 4.1 and Table 4.1 present an overview of this system. The electric wheelchair developed in this research is equipped with remote control system, obstacle recognition system, and automatic tracking system. The author implemented the control of the electric wheelchair in the remote control system and automatic tracking system. Implementation of the VR operation interface in the remote control system and implementation of the obstacle recognition system are described in the previous research [36]. The system is divided into two parts: the electric wheelchair unit and the base station for remote operation. The electric wheelchair is based on TAO LIGHT Ⅱ -m of AISIN SEIKI CO,. LTD. The extension frame is attached to the handle of TAO LIGHT Ⅱ -m and the omnidirectional camera (RICOH R Development Kit) is attached at the tip of frame. The wheelchair is 70 cm in width, 100 cm in length, 135 cm in height, and the height of the lens of the omnidirectional camera is 130 cm. A microcomputer is connected to the controller. The microcomputer read the input of the joystick in the wheelchair and output the operation signal to the electric wheelchair.

4.1 Remote Control System

Telewheelchair wirelessly transmits the omnidirectional image from the electric wheelchair to the base station and the operation signal from the base station to the electric wheelchair to allow remote control. The operation signal was transmitted using Xbee ZB S2C from Digi International K. K. The maximum indoor / urban range is 60 m, and the maximum outdoor / line-of-sight range is 1200 m. This research used CW-1 from IDX Company, Ltd. for transmitting the omnidirectional image. The maximum transmission distance of CW-1 is 30 m. It can transfer full HD (1920 × 1080 pixels) images. Implementation of the VR operation interface at the base station is described in the previous work [36].

4.2 Automatic Tracking System

This research used two Telewheelchair. This research attached the tablet that displayed the artificial reality (AR) marker on the back of the base unit wheelchair. The slave unit wheelchair recognized the AR marker with its attached web camera. The slave unit followed the base unit wheelchair based on the position of the AR marker. The base unit could be remotely operated using HMD or by a controller standing beside a wheelchair.

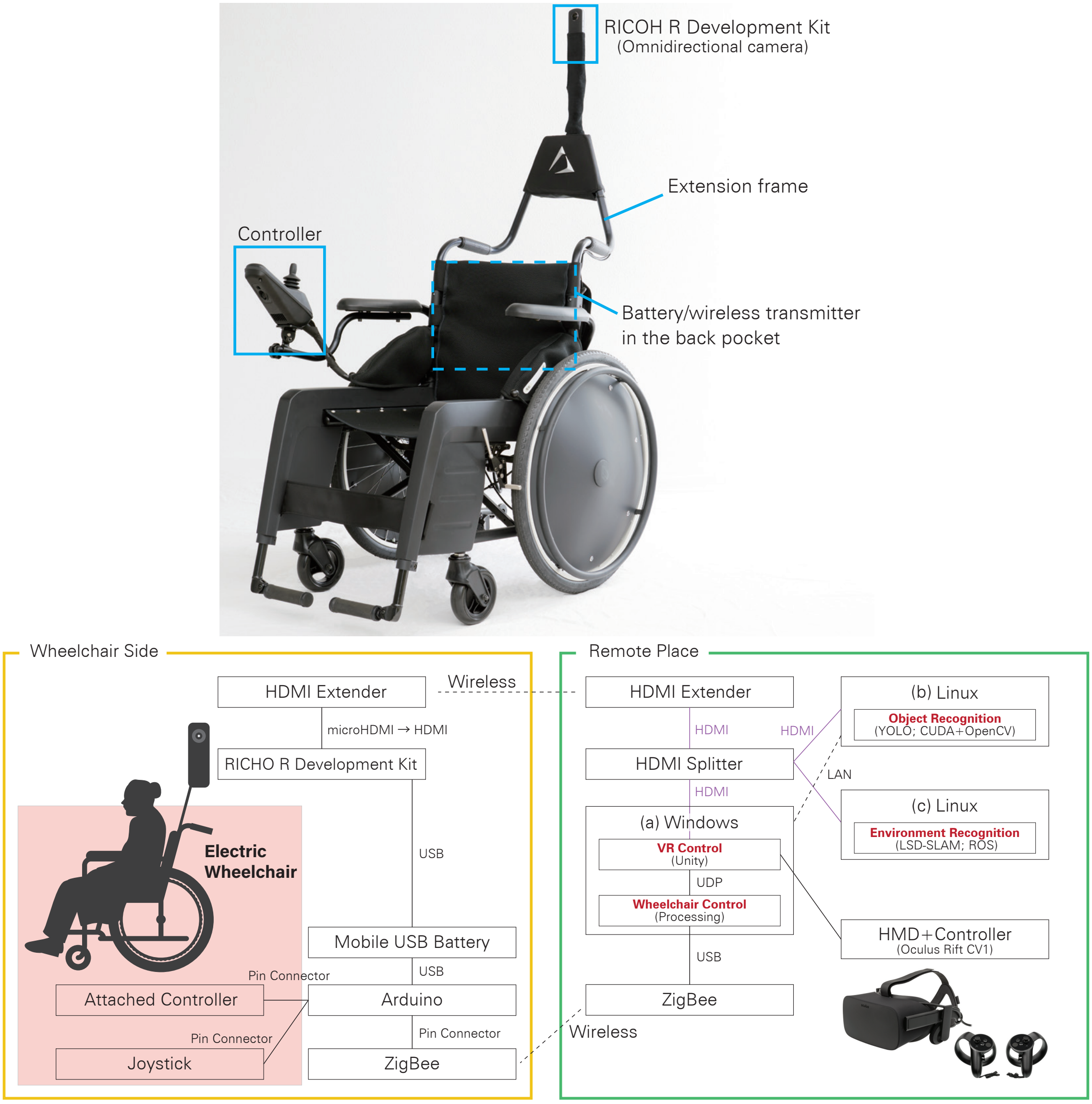

Figure 4.1: Overview of this system.

This research acquired three-dimensional (3D) position coordinates and roll, pitch, and yaw with AR markers using a processor running on a Windows laptop. The speed and direction of rotation of the slave unit wheelchair were calculated using the position of the AR marker. The speed of the slave unit was controlled according to the distance between the AR marker and the slave wheelchair. As shown in the Figure 4.2(a), when approaching the base unit, the slave wheelchair stopped or backed up. The rotation direction of the slave unit was calculated according to the horizontal position of the base unit. The image taken with the camera is divided into three areas as shown in Figure 4.2 (b). The rotation direction was determined by the area where the base unit wheelchair was located. The slave unit wheelchair turned right if the base unit wheelchair was in the right area, went straight if in the middle area, and turned left if in the left area. The rotation speed for turning right and left increased as the base unit wheelchair moved away from the center of the screen. In this system, I divided the camera image in the ratio 7 : 6 : 7, as left turn : straight

Table 4.1: Specifications of the intelligent electric wheelchair.

Electric wheelchair	TAO LIGHT Ⅱ -m [1] (AISIN SEIKI CO,. LTD.) 22 inch, Max speed 6 km/h width 70 cm, length 100 cm, height 135 cm
Omnidirectional camera	RICOH R Development Kit[2] (Ricoh Co., Ltd.) 1920×1080 px 30 fps
Wireless transfer system (operation)	Xbee ZB S2C[3] (Digi International K.K.)
Wireless transfer system (video)	CW-1[4] (IDX Company, Ltd.)
Head mounted display	Oculus Rift CV1[5](Oculus VR, LLC.)
Tablet	Ipad Pro 10.5”[6](Apple Inc.)

ahead : left turn. If the slave unit rotated according to the rotation of the base unit, the slave unit started to turn as soon as the base unit started to turn. By using the proposed divide-by-three method, it was not necessary to record the locus of the base unit, and the slave unit could pass through the path that the base unit passed.

[1] http://www.keepable.net/product/wheelchair/, (last accessed January 8, 2019. In Japanese).
[2] http://ricohr.ricoh/en/, (last accessed January 8, 2019).
[3] https://www.digi.com/products/xbee-rf-solutions/2-4-ghz-modules/xbee-zigbee, (last accessed January 8, 2019).
[4] http://www.idxtek.com/products/cw-1/, (last accessed January 8, 2019).
[5] https://www.oculus.com/rift/, (last accessed January 8, 2019).
[6] https://www.apple.com/shop/buy-ipad/ipad-pro-10-5/, (last accessed January 8, 2019).

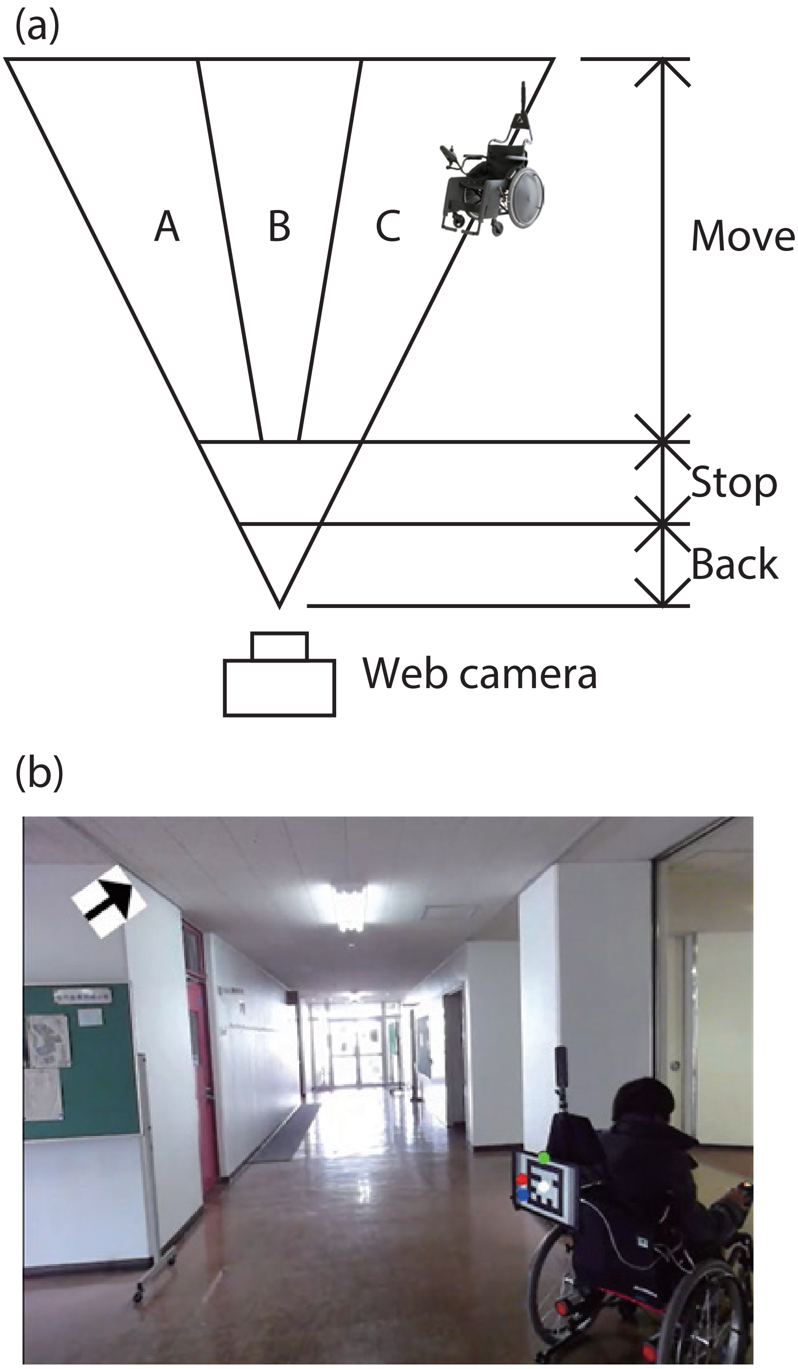

Figure 4.2: System of automatic tracking travel: (a) rear wheelchair utilizes the AR marker to acquire the position of the front wheelchair. By controlling the rear wheelchair according to the position of the AR marker, this research succeeded in following using only the camera, and (b) image of the camera attached to the rear wheelchair.

Chapter 5

Study 1: Evaluation of Operability

This research conducted a user study that runs the course by four operation methods in order to investigate the operability of the remote operation.

5.1 Participants

Twelve participants (four females, eight males, seven of whom were members of my laboratory) aged between 19 and 24 years (M = 20.75, SD = 1.78) participated in the experiment. All participants had normal or corrected vision; five wore glasses and two wore contact lenses. The average height of the participants was 166 cm (SD = 6.19). None of the participants had wheelchair users amongst their family or friends.

5.2 Experimental Design

This research created four operation methods and a course which has six tasks. For each operation method, measure the task execution time. This research attached the reflective markers to Telewheelchair for recording the locus of Telewheelchair using motion capture system by OptiTrack. This research also load a weight of 52.5 kg, i.e., the average bodily weight of a 60-year-old woman. The speed limit of Telewheelchair was 3 km/h.

The course is shown in Figure 5.1. The following six tasks (A-F) are set in the course. Subjects continued running from the start to the goal. Each task was selected from routine actions. The width of aisles and doors were selected based on equipment standards of nursing care facilities stipulated in Japan[7]. This research selected the minimum width from the facility standards. The width of the passage was 1.4 m and that of the door is 0.8 m. This research used chairs (width 60 cm, length 60 cm, height 100 cm) as obstacles.

Task A : Straight task Participants ride through the passageway 1.4 m wide and 6 m long. This study measured the time between the Telewheelchair entering the passageway and reaching the end of it.

Task B : Right turn task Participants turns right at a corner 1.4 m wide. This study measured the time between the Telewheelchair entering the corner and reaching the end of the corner.

[7] `http://www.mlit.go.jp/common/000234983.pdf`, (last accessed January 8, 2019. In Japanese).

Task C : Door task Participants pass the door 0.8 m wide that is narrower than the passageway. They need to drive the wheelchair such that they do not hit the wall. This study hung the sheets 0.3 m wide on each side of the 1.4 m wide passageway and created a 0.8 m wide door. This study measured the time between Telewheelchair passing a point that is 1.4 m before the door and reaching a point 1.4 m after the door

Task D : Left turn task Participants turns left at a corner 1.4 m wide. This study measured the time between Telewheelchair entering the corner reaching the end of the corner.

Task E : Rotation task Participants drive the wheelchair around an obstacle in a clockwise direction. This study place a chair as the obstacle 2 m from the end of a passageway. This study measured the between when Telewheelchair exiting the passageway and turning around the obstacle, until it returns to the passageway.

Task F : Obstacle task Participants need to drive the wheelchair so that it does not hit any obstacles. This study place four chairs as obstacles every 1.3 m from the end of passageway. Participants could avoid the obstacles with any route. This study measured the time between Telewheelchair exiting the passageway and reaching the goal of the route.

This study set up four operation methods (Figure 5.2).

Normal mode This mode is a general operation method operated with the handle of the wheelchair.

Standby mode Subjects operate with the controller by standing next to Telewheelchair.

Display mode Only the front part of the expanded whole omnidirectional image is displayed on the display. Subjects watch only this images and operate the wheelchair with the controller.

HMD mode Subjects wear HMD and operate with controller. Subjects can operate while watching the surroundings freely.

5.3 Procedure

Each participant was briefly informed of the purpose of the study and told that they could abort the study and take a break at any time. Further, they were provided with a consent form to sign and a demographics questionnaire to complete. Subjects traveled the route (Figure 5.1) in four operation modes (Figure 5.2), respectively. Four operation modes were randomly presented to each subject. To identify potential influences on the results, the participants also completed a Kennedy's Simulator Sickness Questionnaire (SSQ) [37] immediately before and after the experiment of display mode and HMD mode.

Normal mode Normal mode is the operation method in which Telewheelchair is operated directly using a handle. At first, participants are given a maximum of 5 min to practice. After that, they drive the test course.

Standby mode Standby mode is the operation method in which the participants stand next to the Telewheelchair and control it with a controller. At first, participants are given a maximum of 5 min to practice. After that, they drive the test course.

Display mode Display mode manipulates the wheelchair while watching the display image of only the front part of the omnidirectional image. Participants use the controller to operate the wheelchair and they do not look at the wheelchair directly. At first, participants are given a maximum of 5 min to practice. They answered the SSQ before driving through the test course. After driving through the test course, they answered the SSQ.

HMD mode HMD mode manipulates the wheelchair while wearing the HMD with the controller. Participants can look around the omnidirectional image. At first, participants are given a maximum of 5 min to practice. They answered the SSQ before driving through the test course. After that, they drove the test course and answered SSQ.

At the end of each operation mode, the participants answered two questions. The first question is the difficulty of operation the wheelchair, on a five-level Likert scale. The second question is the discomfort in the relationship between wheelchair control and wheelchair movement, on a five-level Likert scale. For each question, this research made a free writing field. Participants ranked each operation in order of ease of the operation method after testing the four operation modes.

5.4 Result

5.4.1 Simulator Sickness Questionnaire (SSQ)

This research analyzed the SSQ scores with t-test, and did not find any significant difference between pre-SSQ and post-SSQ scores in display mode and HMD mode. In display mode, SSQ total scores before the experiment averaged 23.7 (SD = 38.1), and the average post-experiment total score was 22.4 (SD = 24.0). In HMD mode, SSQ total scores before the experiment averaged 27.7 (SD = 20.7), and the average post-experiment total score was 38.0 (SD = 44.4).

5.4.2 General Results and Statistical Analysis

The operation path of all participants under all conditions is shown in Figure 5.3. The operation time for each task under all conditions is shown in Figure 5.4.

At first, this research calculate the time required for each task from the data of the motion capture. This research excluded data that is over +2.5SD from the time required for each task as outliers. Five data points were excluded from 72 data points (12 participants $\times$ 6 tasks). This research analyzed the time required for each task, in the standby mode, display mode, and HMD mode, using Friedman's test and multiple comparison. This research used SPSS Statistics version 24 for analysis. It is obvious that there is a difference in the time required, between the normal mode and other control mode because there is a difference the velocity of the wheelchair people are pushing and electric wheelchair. Thus, this research did not include normal mode in the analysis.

The times required for each task in normal mode were shorter than those in other control modes. There were no significant differences in right turn task and door task (Right turn task: $\chi^2(2, 12) = 0.667$, n.s.; Door task: $\chi^2(2, 12) = 0.167$, n.s.).

There was significant difference in straight task ($\chi^2(2, 12) = 8.167$, $p < 0.05$). The result of multiple comparison was that the time required of HMD mode is longer than that in standby mode ($p < 0.05$) in the straight task.

There was significant difference in left turn task ($\chi^2(2, 12) = 6.500$, $p < 0.05$). The result of multiple comparison was that the required time of display mode is longer than HMD mode ($p < 0.05$) in left turn task.

It was found that there was no difference in the required time for many tasks of each operation mode in straight, right turn, door, and left turn tasks. However, there was a significant difference in rotation and obstacle task (Rotation task: $\chi^2(2, 12) = 15.167$, $p < 0.01$; Obstacle task: $\chi^2(2, 12) = 9.500$, $p < 0.01$). The result of multiple comparison was that the time required for display mode is longer than that in standby mode ($p < 0.01$) in rotation and obstacle task. As compared to the normal, standby, display, and HMD modes stagger the pathways of straight and curve. In display mode, participants operated the wheelchair to turn at right angles around the obstacles in rotation and obstacle tasks. In other modes, participants operated the wheelchair to turn around the obstacles smoothly. The times required for rotation and obstacle tasks in display mode is longer than those in standby mode because it take more time to turn at right angles around the obstacles.

5.4.3 Qualitative Results

Figure 5.5 shows the questionnaire results. There was significant difference in answers relating to the difficulty of the operation ($\chi^2(2, 12) = 14.800$, $p < 0.01$). The result of multiple comparison was that operations using display mode are more difficult than normal mode ($p < 0.01$). There were significant differences in responses related to the feeling of discomfort between movement and operation ($\chi^2(2, 12) = 16.851$, $p < 0.01$). The result of multiple comparison was that the operation of display mode causes more discomfort than operations in normal mode ($p < 0.01$). Many participants said normal mode was the easiest in which to operate the wheelchair. Standby mode was considered second-easiest. Display and HMD modes were ranked third and fourth in terms of ease-of-use, but the ranking differed amongst participants. Participants who are familiar with VR found HMD mode easier than display mode, while participants using VR for the first time felt that display mode is easier than HMD mode.

$P_1$1, $P_1$5, and $P_1$8 felt that the normal mode made them more tired than other control modes because in normal mode, they needed to control the heavy wheelchair manually. $P_1$1, $P_1$4, $P_1$8, $P_1$9, $P_1$11, and $P_1$12 felt that display mode was difficult to operate the wheelchair because it difficult to visualize the distance from the wall. $P_1$8 and $P_1$9 perceived a time delay in the video and control in HMD mode.

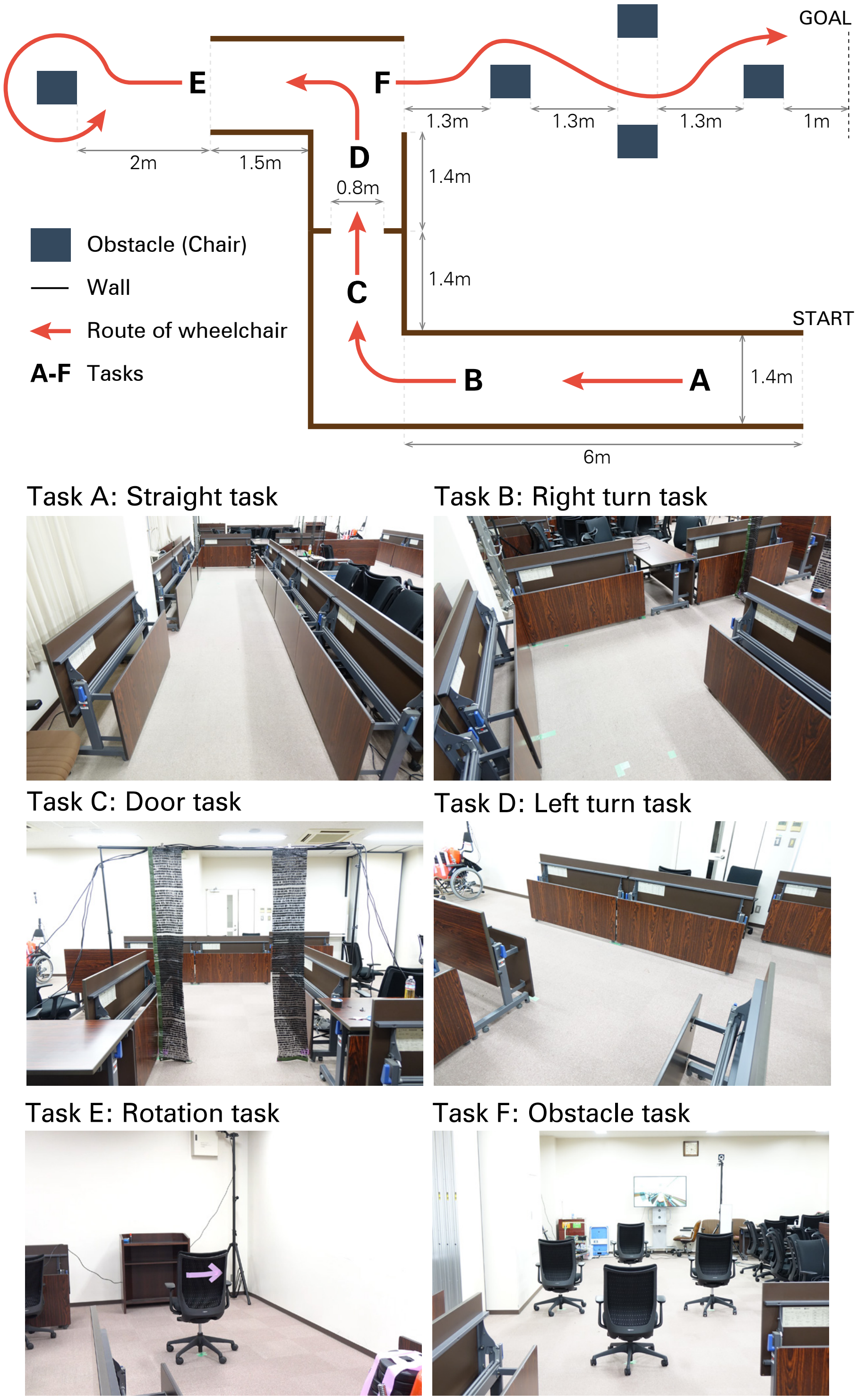

Figure 5.1: Routes used in experiment.

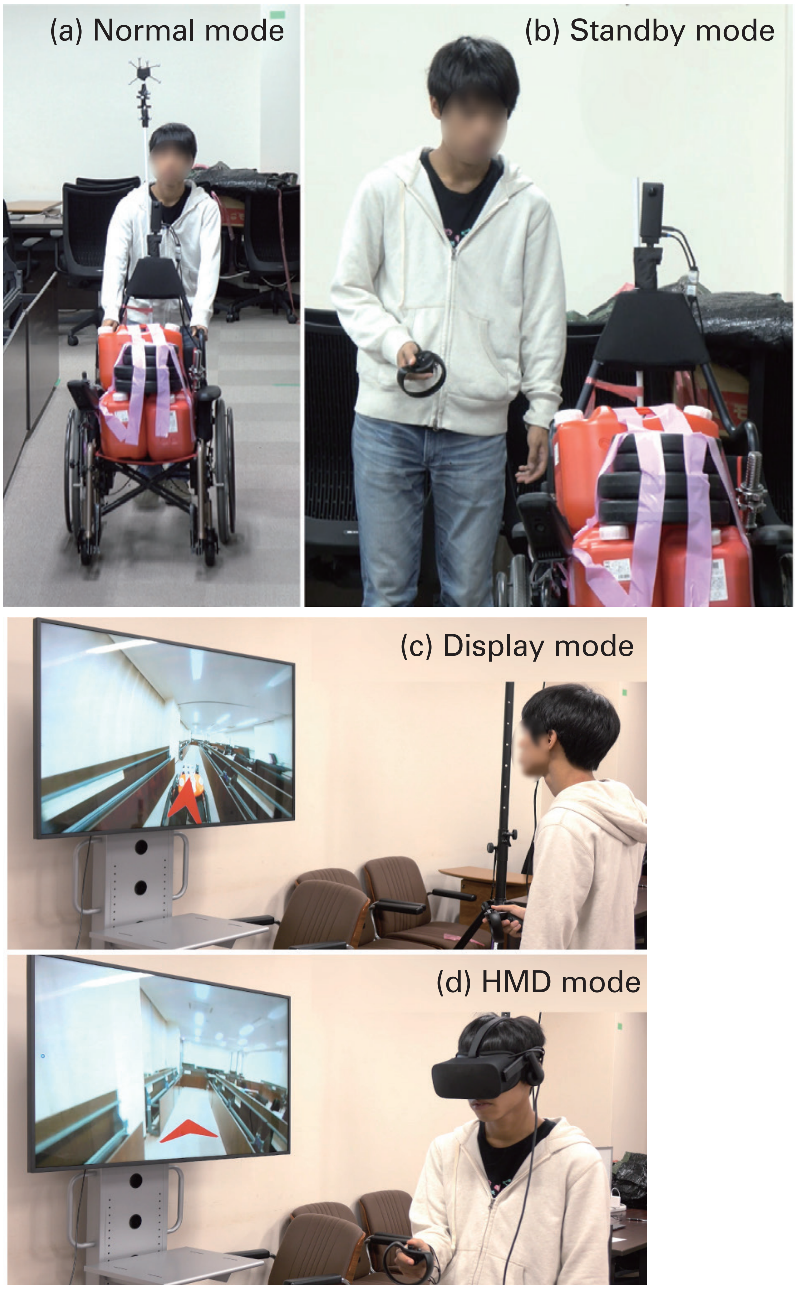

Figure 5.2: Four operation modes.

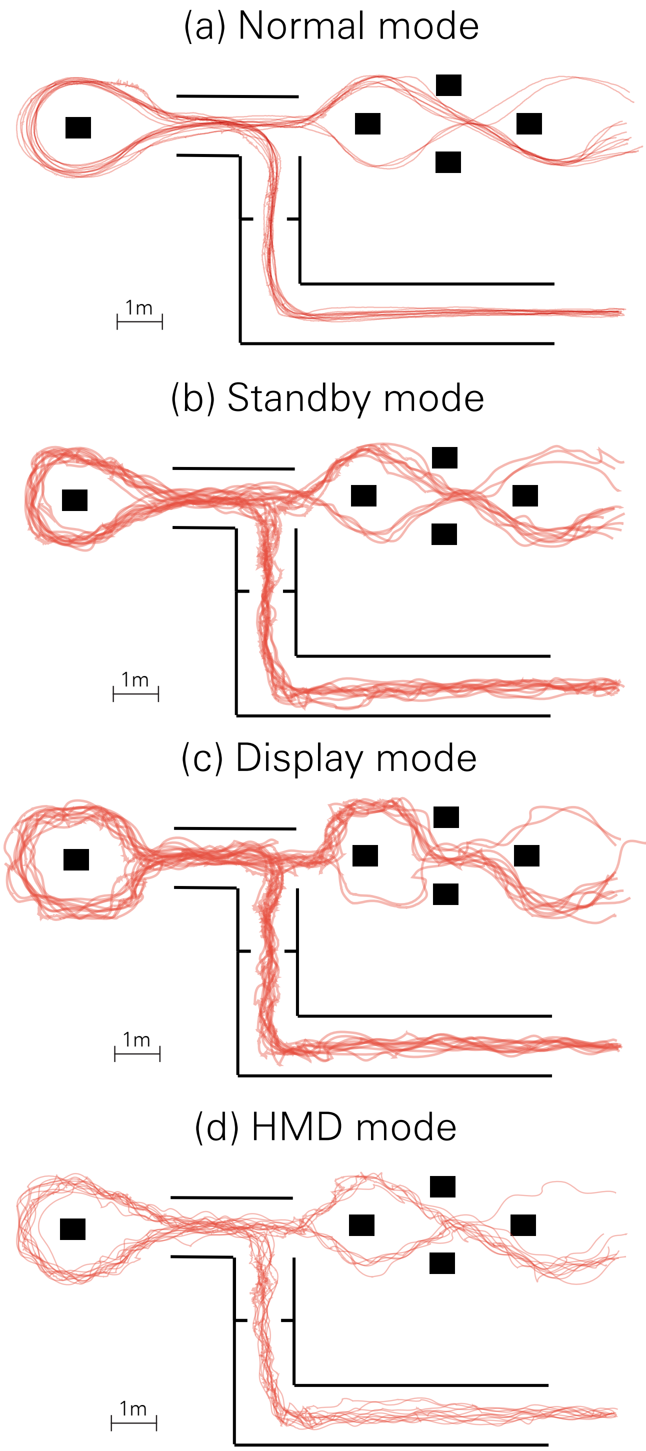

Figure 5.3: Result of operation path.

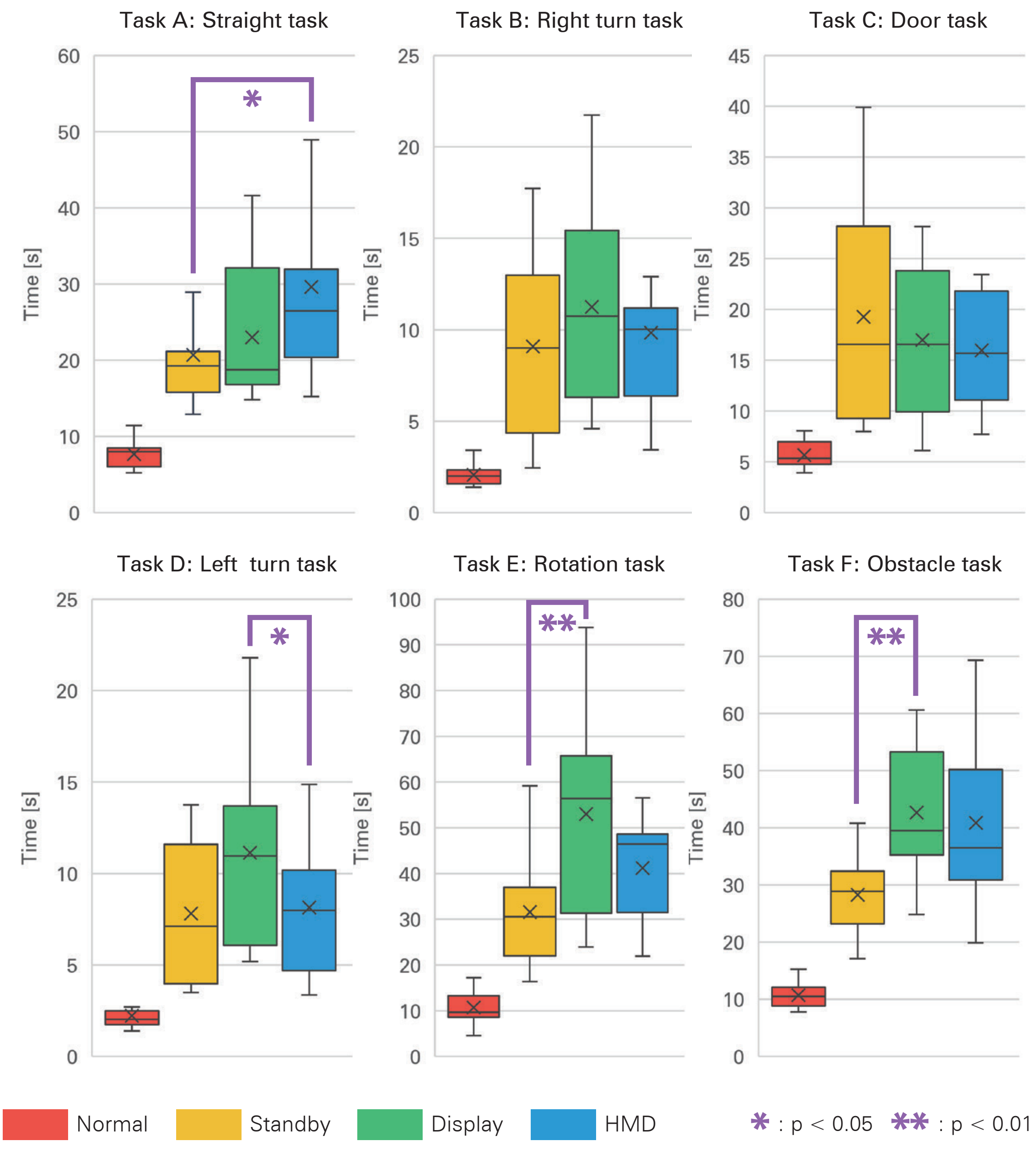

Figure 5.4: Result of operation time for tasks.

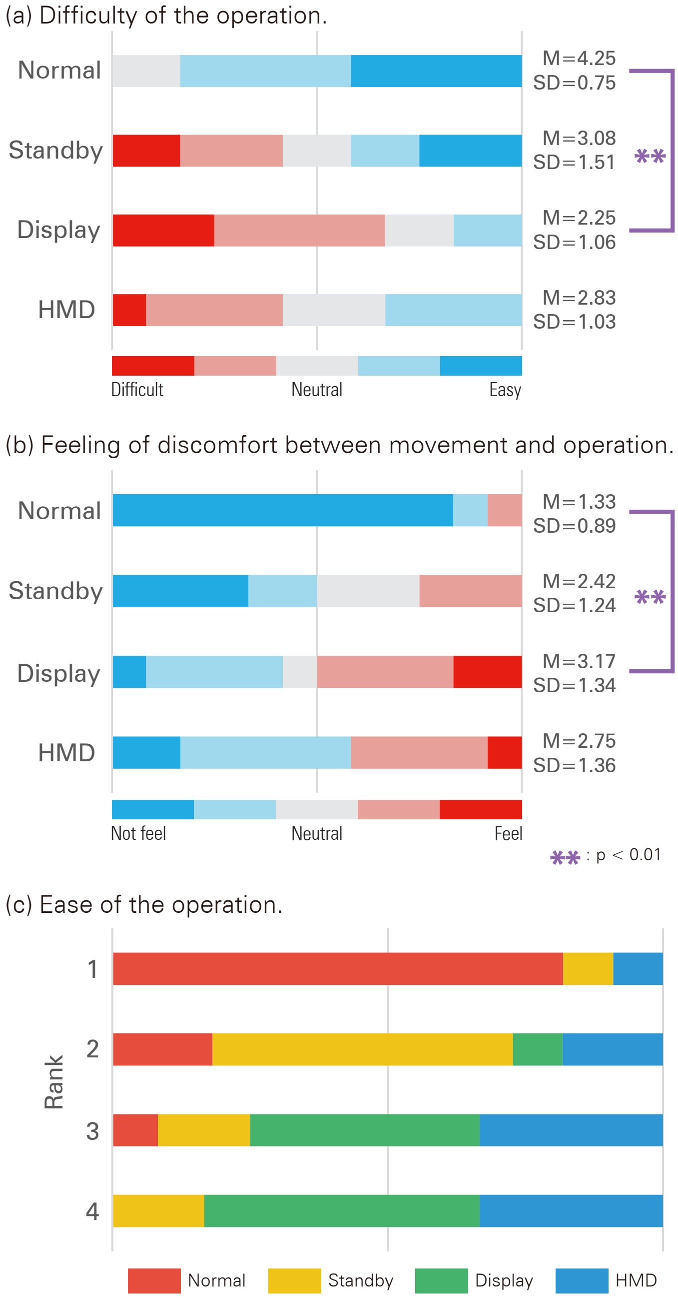

Figure 5.5: Qualitative results.

Chapter 6

Study 2: Problem Finding and Solving

The purpose of this research was to discuss how the intelligent electric wheelchair can be utilized in the nursing care field. First, there was a need to know what problems are present in the nursing care field. Therefore, to identify these problems, this research held a workshop at a nursing home. Next, I considered methods that could solve the problems. Lastly, this research conducted experiments with an intelligent electric wheelchair. This research proposed to discuss the intelligent electric wheelchair more practically by conducting a series of steps from problem finding to practical implementation.

6.1 Problems Finding Phase

6.1.1 Design

The purpose of this research was to reduce the burden on caregivers using an intelligent wheelchair. This research needed to find out what kind of problems there are in the work of nursing care facilities. In the problem finding phase, I aimed to find the problems with wheelchair care at nursing care facilities. Participants of the workshop were staff working at nursing care facilities. Caregivers have a lot of experience and knowledge about nursing care, so it was possible to describe the correct problems in nursing care sites. At the same time, participants subjects considered problem solving methods based on their experience at nursing care facilities. In problem solving phase, I implemented function into wheelchair based on problem solving method.

Caregivers participating in the workshop had little knowledge about automatic driving and artificial intelligence. Therefore, this research also conducted a technical lecture on these topics during the workshop. Technical training included explanations on artificial intelligence and wheelchair operation, as well as an intelligent wheelchair demonstration. In the intelligent wheelchair demonstration, the caregivers participated in three types of experiments: (i) An occupant manipulated a joystick mounted on an electric wheelchair (Figure 6.1 (a)), (ii) A caregiver stood at a distance and controlled the wheelchair using the remote controller (Figure 6.1 (b)), and (iii) An operator simulated automatic driving (Figure 6.1 (c)). Experiments (i) and (ii) were based on the implementation of Study 1. Experiment (iii) was a mode in which a wheelchair automatically moved when the pilot is not nearby.

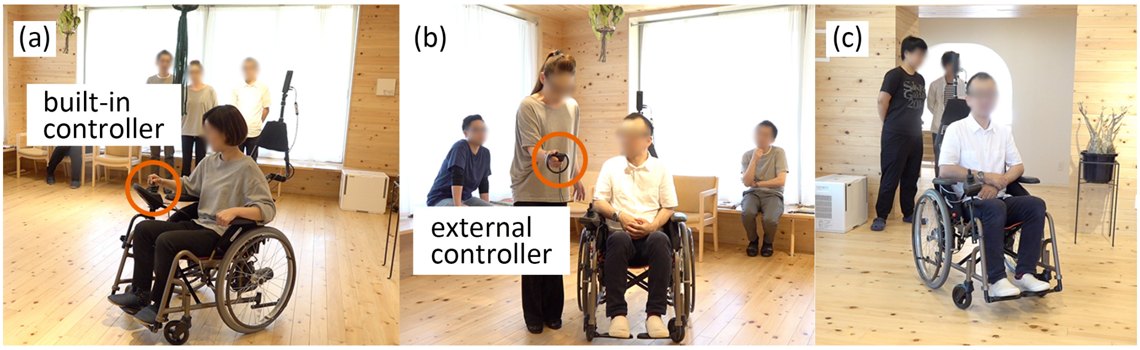

Figure 6.1: Demonstration of the following three types of electric wheelchair to participants: (a) participant rides on an electric wheelchair and operates it with a controller in hand, (b) participant is standing by the wheelchair and using the controller, and (c) participant rides on a wheelchair operated remotely.

It is noted that instead of implementing a self-driving electric wheelchair, this research actually conducted an experiment that simulated the self-driving environment. An operator controlled the wheelchair from a remote location. However, the participants were not told that the control operation was manually controlled from a remote location; therefore, participants believed that the electric wheelchair was being driven automatically. The aim of experiment (iii) was to encourage participants to experience operations like automatic driving and to have deeper understanding of automatic driving. The target comprehension level of participants after receiving technical training was an understanding of the meaning and purpose of artificial intelligence and the outline of the intelligent wheelchair. Participants were asked to consider solutions to problems before and after technical training. Following their technical training, I asked them to respond using the artificial intelligence information they learned in the course and their knowledge of automatic driving.

6.1.2 Procedure

Each participant was briefly informed of the purpose of the study and was informed that they could stop the study and take a break at any time. Further, they were provided with a consent form to sign and a demographics questionnaire to complete.

Initially, the participants were asked to write out their career experience and problems they have encountered. The response time was 15 min. Next, the participants were asked to write a method capable of solving a nursing care problem. I asked them to write three problems that they wanted to solve, and their proposed solutions. The problems they wanted to solve were expected to be based on the problem that they wrote. The response time was 30 min. Next, I presented a technical training demonstration using the electric wheelchair. The duration of the technical course was 15 min and the demonstration was 45 min. After the three types of demonstrations were completed, participants were asked to provide their impressions of each demonstration. Lastly, I asked the participants to write a method capable of solving a nursing care problem. The problem solving method was to be based on the material learned in the technical course. It included up to three problems that participants wanted to solve. The response time was 30 min. All response times were sufficient answer the questions.

Table 6.1: Summary of workshop participants on intelligent wheelchair for caregivers. *"Chief" is responsible for supervising caregivers in nursing homes

	Sex	Age	Position at the nursing home	Length of service (year)
$P_2 1$	F	29	Caregiver	7
$P_2 2$	F	23	Former caregiver	3
$P_2 3$	M	33	Chief*	4
$P_2 4$	M	42	Chief	20
$P_2 5$	F	63	Chief	20
$P_2 6$	M	44	Chief	12

6.1.3 Participants

Six participants (three females and three males) with ages between 23 and 63 years (M = 39, SD = 14.2) participated in the experiment (Table 6.1). All participants were caregivers. All participants were employed in nursing care facilities that conducted workshops. The average years of employment was 11.5 years (SD = 7.2). Four participants did not know about Telewheelchair in advance and two participants knew a little about it. All participants spoke Japanese.

6.2 Problems Solving Phase

6.2.1 Design

In this phase, the aim was to implement and evaluate methods found during the problem finding phase. Caregivers who participated in the problem finding phase raised a common problem: having fewer hours to care for older adults. For example, the duties of a caregiver consisted of a large number of tasks, such as working alone to assist three older adults with their diets, and assisting with the bathing of more than 30 people a day. With this workload, the caregiver may not had time to communicate well with the older adults. Hence, to increase the time spent for meals, nursing care, and bathing assistance, I considered shortening the traveling time of the wheelchair.

To shorten the travel time of the wheelchairs, this research implemented an automatic tracking travel system in the intelligent wheelchair. The caregiver could simply operate the first wheelchair, and a second rear wheelchair automatically followed; hence, all the wheelchairs could be operated simultaneously. In a nursing home care facility, many wheelchairs have to be moved at the same time when moving the care recipients from a room to a dining room or a bathroom. At such times, controlling a plurality of wheelchairs simultaneously could shorten travel time.

6.2.2 Procedure

I informed the participant about the study and obtained their consent as described above. First, participants were asked to introduce themselves. Next, the experimenter introduced the functions of the intelligent wheelchair to the participants and explained the demonstration to be conducted later. After the explanation was completed, I demonstrated the automatic tracking travel system. The demonstration time was 45 min. Finally, I asked the

Table 6.2: Summary of workshop participants on follow-up driving for caregivers

	Sex	Age	Position at the nursing home	Length of service (months)
$P_3 1$	M	22	Caregiver	3
$P_3 2$	M	21	Caregiver	21

participants to provide their impressions of the demonstration.

6.2.3 Participants

Two participants (two males), average age 22 years, participated in the experiment (Table 6.2). Both participants were caregivers. Both participants were employed in nursing care facilities that conducted workshops. One participant did not have prior knowledge of the Telewheelchair, and another participant knew a little. Both participants spoke Japanese.

6.3 Findings

6.3.1 Problem Finding Phase

Problems of care

In this section, this research present the problems at the nursing care facility that caregivers identified during the workshop. First, the participants described the privacy of the older adults. $P_2 2$ said, "*We need to give care in the toilet, but from the privacy point of view it is difficult to stay in the toilet.*" $P_2 4$ answered that taking care of meals is an example, "*Consideration must be given so that the people do not feel like they are being watched while I am observing the situation.*"

Next, participants described the time available for each older adult. $P_2 2$ and $P_2 5$ responded about the amount of work done by one caregiver, "*It is necessary for one person to change more than five diapers.*" ($P_2 2$), "*I do three person meals assistance at the same time.*" ($P_2 2$), and "*There was no time to communicate with the older adults because only two people assisted the bathing of 30 people a day.*"($P_2 5$). $P_2 4$ said about various assistance, "*the time spent per capita is short, because doing a lot of work within the day seems like non-stop work.*"

$P_2 2$ and $P_2 3$ felt that caregivers were always considering how to ensure older adults to live safely. $P_2 2$ said, "*Caregivers talk to the older adults sitting on a wheelchair from behind them*". $P_2 3$ said, "*Caregivers are always working hard because they care about multiple older adult people; but, it is necessary to have the older adults with the caregiver feel safe, so they should always respond slowly and clearly, with a smile.*" $P_2 2$ answered, "*Caregivers should always accompany the older adults for their safety.*"

Problem solving methods

This research first describe the problem solving methods given by the participants before the technical learning seminar. $P_2 1$, $P_2 2$ and $P_2 6$ cited the problem of sitting when the older adults are in a wheelchair. Because $P_2 1$ wants to have the older adults sit comfortably in the wheelchair with little effort, he proposed a wheelchair whose seat surface could be adjusted. $P_2$6 replied, "*We will make the seat height changeable and make the cushioning material adjustable.*" $P_2$4 and $P_2$6 proposed a solution for transferring. $P_2$4 replied, "*In order to enable transfer without relying on the caregiver's skills, we will make wheelchairs with sizes and functions suited to the older adults.*" $P_2$6 said, "*I want the wheelchair's footrest and foot support to be able to close together automatically so as to solve the problem of moving the wheelchair from the bed.*" $P_2$1 and $P_2$5 mentioned the time and labor of movement. $P_2$1 said that the trouble with moving the wheelchair can be solved if the wheelchair can be operated close to the older adults automatically. $P_2$5 replied, "*I hope all the assistance can be operated by a voice control system.*" $P_2$3 answered, "*I want to walk in parallel rather than pushing the wheelchair from the back; I want the wheelchair to be operated remotely.*"

After the technical learning seminar, the problem-solving methods were discussed. $P_2$1 and $P_2$2 said that the older adults should be able to transfer alone and go to their destination. They said that it would be significantly effective to have automatic driving, voice recognition, wheelchair tracking, and calling for help functions on the wheelchair itself. $P_2$5 and $P_2$2 added a comment about dementia. $P_2$5 said, "*Older adults with dementia will forget their location and wheelchair operation procedures. For this kind of person to maneuver the wheelchair, it is necessary to control it by speech recognition. Furthermore, functions of remembering the route and driving automatically are desirable.*"

Intelligent wheelchair demonstration

This research first performed the demonstration with the control operation of using a joystick mounted on an electric wheelchair. $P_2$2 felt, "*I could drive with my own will.*" $P_2$5 answered, "*I can operate the driving just with my fingers, so people without paralysis in hand may also control it themselves.*" $P_2$2, $P_2$6 replied, "*It is peace of mind.*"

Next, this research performed the demonstration with the external wheelchair controller operated by an experimenter standing next to the participants. $P_2$2 and $P_2$5 answered, "*When seated in the wheelchair, I was relieved to see the face of the other person and to talk with him.*" $P_2$3 said, "*The operation became easy when I became familiar with the controller.*" $P_2$5 answered, "*It is difficult to get used to the operations when I am using the controller.*" $P_2$3 and $P_2$4 answered, "*The operation of the controller is difficult so sometimes I cannot control the wheelchair well.*"

Finally, the participants experienced a demonstration simulating automatic driving. $P_2$2 did not feel like a human. $P_2$3 replied, "*It is more comfortable than being operated using the controller.*" $P_2$5 answered, "*It will be fun to move in this way because I can do other things while riding.*" On the other hand, there were opinions such as "*I feel anxiety that there is no trust relationship with someone.*" ($P_2$4)

6.3.2 Problem Solving Phase

Participants experienced a wheelchair equipped with cooperative operation functions. $P_3$1 felt that, "*It could be effective if used in nursing care facilities. In the cafeteria, I felt that this way could lead all of us to the dining room at almost the same time, without deciding the priority among the older adults. It may also change the living situation of people who cannot push wheelchairs by themselves. Those who live in nursing homes are often in their rooms, but I think that if they have this wheelchair they will be able to go shopping and go* *out at any time."* $P_3$2 mentioned that, "*It is natural to go straight, but I hope there will be a function that prevents it from hitting obstacles on the side or getting stuck even if it hits someting. For those with a paralyzed body, there is a possibility of falling, in that case I would like the wheelchair to stop urgently."*

Chapter 7

Study 3: Interview with Older Adults

7.1 Goal

The purpose of the experiment in this section was to investigate how older adult people accept intelligent electric wheelchairs. Artificial intelligence and automatic driving are relatively familiar to young people. However, they are not familiar to older adults; hence, it was unknown how the older adults feel about the new wheelchair. By experiencing the new electric wheelchair this research developed, this research can learn how older adults feel about technologies such as automatic driving and artificial intelligence. In addition, because study 1 were conducted on the same wheelchair from the viewpoint of the pilot, I can compare those results with the current experiment from the passenger's point of view.

7.2 Design

In the study 1, an experiment on the operability of the electric wheelchair was conducted. A remotely controllable electric wheelchair was developed. Four operation methods and experiments on operability were conducted. This research conducted experiments using three manipulation methods out of the four methods conducted in study 1: (i) Normal mode. This mode is a general operation method operated with the handle of the wheelchair (Figure 7.1(a)); (ii) Stand by mode. experimenter operate using the controller while standing next to the wheelchair (Figure 7.1(b)); and (iii) HMD mode. experimenter wear an HMD and operate the external controller. experimenter can operate while freely watching the surroundings (Figure 7.1(c)). The older adults rode in the wheelchairs while the experimenter controlled it. The wheelchair traveled straight through at corridor inside the nursing home for 11 m from the start point, performed a U-turn, and returned straight 11 m to the goal point (Figure 7.2). The width of the corridor was 2.1 m.

7.3 Procedure

I informed the participant about the study and obtained their consent as described above. Participants experienced wheelchair operation in the order of Normal mode, Standby mode, HMD mode. After experiencing each maneuvering mode, the participants were asked to

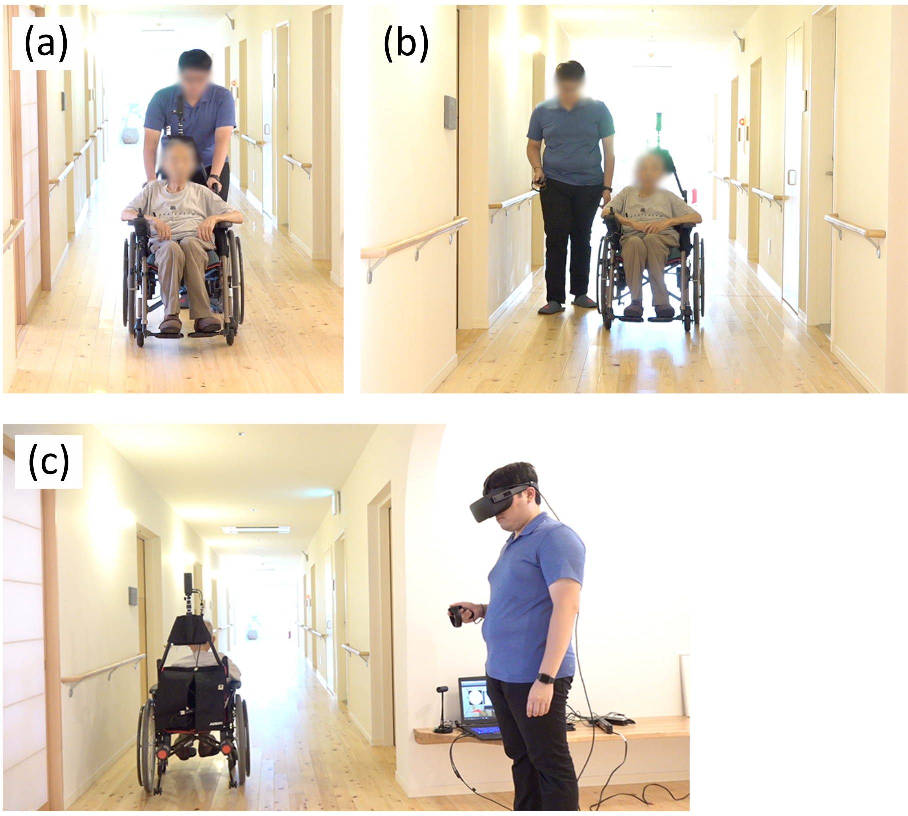

Figure 7.1: This research carried out the following three pattern experiments with the participants on a wheelchair: (a) push the wheelchair from behind, (b) operate with the controller while walking or standing by the wheelchair, and (c) operate away from the wheelchair using VR.

Table 7.1: Summary of intelligent wheelchair demonstration participants for care receivers

	Sex	Age
$P_4 1$	F	92
$P_4 2$	M	93

answer the question about whether the ride was good or fearful, or whether they would want to use the wheelchair again.

7.4 Participants

Two participants (one female, one male), with an average age of 92.5 years, participated in the experiment (Table 7.1). Both of the participants lived in the nursing facility where the workshop was conducted. Participants required wheelchairs and could maneuver wheelchairs on their own if they were indoors. Participants could conduct commonplace conversations and write without problems. The wheelchair usually used is Next Core Puchi [8] . All participants spoke Japanese.

[8] http://www.matsunaga-w.co.jp/search/detail_64.html, (last accessed January 8, 2019. In Japanese).

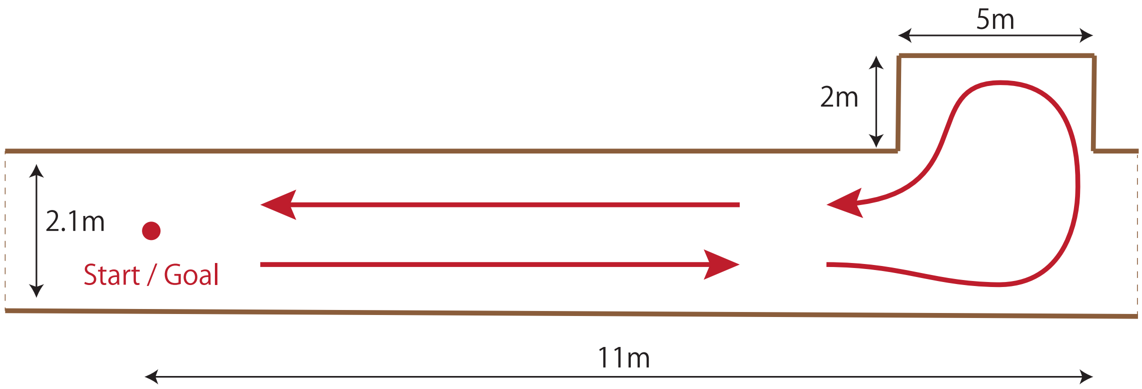

Figure 7.2: The course this research used for the experiment at the nursing home. In the experiment this research traveled back and forth 11 m in a corridor with a width of 2.1 m. The turning point is in the hall and the width of the corridor is widened.

7.5 Findings

First, the participants experienced the wheelchair that the experimenter pushed from behind. $P_4$1 answered, "*It's the easiest to get on the wheelchair I have ever had.*" $P_4$2 did not feel any change. Next, the participants got on a wheelchair operated by the external controller. $P_4$1 said, "*It was exhilarating, and I felt safe because there was the person next to me.*" $P_4$2 answered, "*The wheelchair was slightly shaky. There was no fear, but I think it is not much relative to the presence of a person next to me.*" Finally, the older adults got on a remotely controlled wheelchair. $P_4$1 said, "*I think I'm a little afraid when there is no one next to me now, but if I get used to it I think that it is okay. I want to go outside but I was still too scared to do that.*" $P_4$2 said, "*I was afraid of what will happen because the wheelchair is not under my control. But as the performance of the wheelchair rises, I think that fear may disappear.*" $P_4$1 answered that the stand-by mode was the best among the three riding methods.

Chapter 8

Discussion

8.1 Required Time for Operation

This research researched the time required for each task in study 1. In door and right trun tasks, there is no significant difference between standby, display and HMD modes. However, display mode takes more time than standby mode during operations including turning over 90 degrees (rotation and obstacle task). It is caused by participants attempting to turn squarely around the obstacles at display mode. They could turn the wheelchair diagonally because they could look around it at standby mode and HMD mode. However, I consider that they operated the wheelchair to turn squarely because they could not look around wheelchair in display mode. Therefore, it can be said that there is no difference in any operation mode as long as only straight ahead and right-angle curve paths are considered. However, I believe that standby mode and HMD mode are superior to display mode in an environment that include not-right-angle curves.

8.2 Difficulty in Operation

This research enquired about the difficulty of the operation and feeling of discomfort between movement and operation as part of the qualitative evaluation. From the result of study 1, this research found that display mode is more difficult than normal mode. I consider that this is caused by difficulty in sensing the perspective in display mode. It shows that standby mode and HMD mode are superior to display mode from the point of view of difficulty of the operation.

Some participants felt that operating the wheelchair was difficult. There were some opinions that it was difficult to obtain perspective-related information in at display mode and HMD mode. The image shown on display is distorted with wide angle lens in order to be able to indicate a wide range of wheelchair viewpoint on a single display. I consider that participants could not sense the perspective because of distortion. To solve this problem, this research need to use multiple displays to show a wide-angle view without distortion. In HMD mode, the operator is unable to see the binocular vision even if they use the HMD because we use a monocular omnidirectional camera to record the view from the wheelchair. Therefore, participants could not get accurate perspective-related information. This research need to use the 3D omnidirectional cameras to realize binocular vision.

In addition, some participants perceived a delay between the operation of the controller and the movement of the actual wheelchair. The base wheelchair of Telewheelchair is accelerated slowly to prevent a jump start even if the controller moves suddenly. Therefore, some participants who try to control the electric wheelchair feel that it is slow to accelerate. In addition, the delay also occurs due to video transmission and image processing in Unity. When the operator performs an operation to turn, they feel a sense of incongruity of operation. To resolve this, this research need to add image processing functionality such as pre-move the image to offset the gap between the wheelchair's movement and image delay.

This research also found that standby mode and HMD mode have similar difficulty of control. Therefore, we can choose the operation mode depending on the use case. Operators could use HMD mode when they control the wheelchair remotely and standby mode when controlling the wheelchair while standing near it. Standby mode reduces the burden of the care giver because it needs lower human power than control the wheelchair manually.

8.3 Busyness of caregivers

In this section, this research discuss the problems found during the practical workshop to find out how to make use of the intelligent electric wheelchair. In the opinion of the caregivers, the time to devote to nursing care for each older adults is less because the actual nursing care work includes many aspects such as excretion aid, meal assistance, and bath assistance. Furthermore, in nursing care facilities, the number of older adults who need care from each caregiver is large because of caregiver shortage. As $P_2 2$ and $P_2 5$ stated, caregivers have shorter contact times with each older adults. Also mentioned from $P_2 5$, it is difficult for a caregiver to communicate sufficiently with older adults. Moreover, if communication becomes impossible and it becomes like routine work, it may lead to at psychological burden on the older adult. In order to increase the time to be in contact with the older adults, it is necessary to reduce the time taken for nursing care.

Thus, this research provided possible solutions for using an electric wheelchair to reduce person movement time. In nursing care facilities, there are many opportunities to move multiple wheelchairs at the same time from, for example, the living room to the dining room and the bathroom. If the caregiver can shorten the time it takes to move the wheelchairs, he or she can increase the time for other nursing care work. In order to shorten the time it takes to move, this research installed a cooperative-operation function on an electric wheelchair. The function enables the system to move multiple wheelchairs at the same time, so the time it takes the caregiver to make the moves decreases. This research conducted a demonstration and interview with caregivers using an electric wheelchair equipped with the cooperative operation function. As a result of the interview, the participants recognized the usefulness of the cooperative-operation function. However, the caregivers believed it to be difficult for a single caregiver to monitor multiple wheelchairs simultaneously. Thus, a future improvement will be a monitoring system to prevent a passenger from falling down and accident.

8.4 Operation Method

The participants of the workshop provided many opinions on the operation method. As $P_2 5$ and $P_2 2$ described, there are older adults with dementia living in nursing homes. Such older adults cannot remember how to operate devices, so it is difficult to use an electric wheelchair. In order to enable such older adults to use the electric wheelchair, it is necessary to be able to control the electric wheelchair without remembering the operation method themselves. A voice manipulation function was thought to be effective solution, because even older adults with dementia can control it thorough voice commands. In addition, older adults with dementia cannot remember the location of their room, so it is difficult for them to act alone. An electric wheelchair that could automatically advance to the destination, by voice control and a navigation system, can reach the destination even for an older adults who has forgotten the location of the room.

From the workshop, changes to the operation method were suggested so that the older adults can be relieved of their fears. As mentioned from $P_2 2$ and $P_2 3$, it is important to make it possible for older adult people to feel secure. Also mentioned from $P_2 2$, when a caregiver is assisting a wheelchair and pushing it from the back, the caregiver often talks to the older adult when behind their back. From behind, the older adults cannot see the caregiver's facial expression, which makes it difficult to communicate. Therefore, this is possibility a situation that makes the older adults become uneasy. Hence, this research implemented a function that permits the caregiver to stand next to the wheelchair and steer it. Standing next to the wheelchair makes it easier to communicate with the older adults. This research implemented this control function using an external controller and demonstrated it to the older adults. After this demonstration, the older adults expressed that they felt safe because they could see the face of the operator.

8.5 Psychology of the Older Adults

This research conducted experiments with the older adults in the nursing home using the intellectualized electric wheelchair developed previously. Overall, the older adults expressed a positive opinion. When the experimenter assisted by standing next to the wheelchair, there was a sense of safety, due to the presence of a person. In the case of remote control, the older adults felt fear. However, $P_4 1$ thought that the fear may disappear if one became accustomed to the remote operation, and $P_4 2$ said that the fear would go away if operational safety is higher. Therefore, this research inferred that older adults might be more accepting of the remote control if safety could be ensured. It seemed that older adults positively understand the evolution of nursing care devices by technologies such as remote control. This research need to experiment with the electric wheelchair equipped with automatic driving and artificial intelligence, to see if the older adults will accept it. However, I must always be conscious of the necessity of enhancing the safety of intelligent electric wheelchair.

8.6 Limitation

The transmission distance in the current system extends up to 30 m, depending on the specification of the wireless device. We cannot operate wheelchairs when there is a physical barrier between them and their controllers. In the current system, I communicate with wheelchair directly via the wireless device on it. This research need to use Wi-Fi or 4G network to enable functionality over longer transmission distance.

In case where a caregiver remotely controls the wheelchair, they could not correspond if the care recipient on a wheelchair performs dangerous actions. The wheelchair user may operate the controller attached to the wheelchair, or suddenly stand up or fall down. In order to allow caregivers to monitor the state of the wheelchair user, it is necessary to attach the camera that photographs the care recipient or a sensor that detects motion.

This research only held a one-day workshop and this research have not conducted long-term experiments in study 2 and 3. Whether the intelligent electric wheelchair proposed by us can be used for nursing care work cannot be determined unless caregivers use it for a longer term. This research have to conduct more experiments at a nursing facility for few month.

The participants did not have a wide range of symptoms in study 3. The older adults who participated in the experiments were able to talk and able to maneuver wheelchairs on their own. Furthermore, the number of subjects in some experiments was as few as two. There were some older adults living in the facility who had severe dementia and others who could not get up by themselves. For older adults with such severe disabilities, this research need to experiment to see if intelligent electric wheelchairs are useful. For that reason, this research need to design experimental methods for those who cannot talk well.

Chapter 9

Conclusions

This research developed a novel electric wheelchair system, called Telewheelchair, that includes remote control and AI support. In this study, I experimented with four operation modes to evaluate controllability. This research found that HMD mode is superior as compared to using display mode to control a wheelchair remotely. This research also found that the method to operate while standing next to the wheelchair is as useful as using HMD. This research conducted a workshop for caregivers and tried to identify some problems of nursing care and some solutions. There were some major problems described participants, however in the experiments this research focused on the problem of a caregiver's workload. In order to solve this problem, this research implemented cooperative-operation function to the wheelchair and demonstrated it to caregivers. The usefulness of proposed wheelchair was shown. In the interviews with older adults, this research found that the older adults positively accepted the intelligent electric wheelchair. In future, this research can enhance the functionality of the system by adding an AI function and certain other functions that are crucial in nursing care sites in order to reduce the burden of the caregivers. This research believe that Telewheelchair can contribute significantly towards improving the quality of life of wheelchair users while keeping them safe, and simultaneously aid caregivers in their responsibilities.

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